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Software Intensive Systems Cost and Schedule Estimation

Final Technical Report SERC 2013-TR-032-2

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14. ABSTRACT

This is the 2nd of two reports that were created for research on this topic funded through SERC. SERC-TR-2013-032-2 (current report), included the "Software Cost Estimation Metrics Manual." This constitutes the 2012-2013 Final Technical Report of the SERC Research Task Order 0024, RT-6: Software Intensive Systems Cost and Schedule Estimation. Estimating the cost to develop a software application is different from almost any other manufacturing process. In other manufacturing disciplines, the product is developed once and replicated many times using physical processes. Replication improves physical process productivity (duplicate machines produce more items faster), reduces learning curve effects on people and spreads unit cost over many items. Whereas a software application is a single production item, i.e. every application is unique. The only physical processes are the documentation of ideas, their translation into computer instructions and their validation and verification. Production productivity reduces, not increases, when more people are employed to develop the software application. Savings through replication are only realized in the development processes and on the learning curve effects on the management and technical staff. Unit cost is not reduced by creating the software application over and over again.

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Analysis based on data from the DoD Software Resource Data Report.

SUMMARY

This is the 2nd of two reports that were created for research on this topic funded through SERC.

The first report, SERC-TR-032-1 dated March 13, 2012, constituted the 2011-2012 Annual Technical Report and the Final Technical Report of the SERC Research Task RT-6: Software Intensive Systems Data Quality and Estimation Research In Support of Future Defense Cost Analysis.

The overall objectives of RT-6 were to use data submitted to DoD in the Software Resources Data Report (SRDR) forms to provide guidance for DoD projects in estimating software costs for future DoD projects. In analyzing the data, the project found variances in productivity data that made such SRDR-based estimates highly variable. The project then performed additional analyses that provided better bases of estimate, but also identified ambiguities in the SRDR data definitions that enabled the project to help the DoD DCARC organization to develop better SRDR data definitions.

In SERC-TR-2012-032-1, the resulting Manual provided the guidance elements for software cost estimation performers and users. Several appendices provide further related information on acronyms, sizing, nomograms, work breakdown structures, and references.

SERC-TR-2013-032-2 (current report), included the "Software Cost Estimation Metrics Manual." This constitutes the 2012-2013 Annual Technical Report and the Final Technical Report of the SERC Research Task Order 0024, RT-6: Software Intensive Systems Cost and Schedule Estimation

Estimating the cost to develop a software application is different from almost any other manufacturing process. In other manufacturing disciplines, the product is developed once and replicated many times using physical processes. Replication improves physical process productivity (duplicate machines produce more items faster), reduces learning curve effects on people and spreads unit cost over many items.

Whereas a software application is a single production item, i.e. every application is unique. The only physical processes are the documentation of ideas, their translation into computer instructions and their validation and verification. Production productivity reduces, not increases, when more people are employed to develop the software application. Savings through replication are only realized in the development processes and on the learning curve effects on the management and technical staff. Unit cost is not reduced by creating the software application over and over again.

This manual helps analysts and decision makers develop accurate, easy and quick software cost estimates for different operating environments such as ground, shipboard, air and space. It was developed by the Air Force Cost Analysis Agency (AFCAA) in conjunction with DoD Service Cost Agencies, and assisted by the SERC through involving the University of Southern California and the Naval Postgraduate School. The intent is to improve quality and consistency of estimating methods across cost agencies and program offices through guidance, standardization, and knowledge sharing.

The manual consists of chapters on metric definitions, e.g., what is meant by equivalent lines of code, examples of metric definitions from commercially available cost models, the data collection and repository form, guidelines for preparing the data for analysis, analysis results, cost estimating relationships found in the data, productivity benchmarks, future cost estimation challenges and a very large appendix.

Software Cost Estimation Metrics Manual

Analysis based on data from the DoD Software Resource Data Report

This manual describes a method that takes software cost metrics data and creates cost estimating relationship models. Definitions of the data used in the methodology are discussed. The cost data definitions of other popular Software Cost Estimation Models are also discussed. The data collected from DoD's Software Resource Data Report are explained. The steps for preparing the data for analysis are described. The results of the data analysis are presented for different Operating Environments and Productivity Types. The manual wraps up with a look at modern estimating challenges.

Contents

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Software Cost Estimation Metrics Manual

Analysis based on data from the DoD Software Resource Data Report

1 Introduction

Estimating the cost to develop a software application is different from almost any other manufacturing process. In other manufacturing disciplines, the product is developed once and replicated many times using physical processes. Replication improves physical process productivity (duplicate machines produce more items faster), reduces learning curve effects on people and spreads unit cost over many items.

Whereas a software application is a single production item, i.e. every application is unique. The only physical processes are the documentation of ideas, their translation into computer instructions and their validation and verification. Production productivity reduces, not increases, when more people are employed to develop the software application. Savings through replication are only realized in the development processes and on the learning curve effects on the management and technical staff. Unit cost is not reduced by creating the software application over and over again.

Software Cost Estimation

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There is no good way to perform a software cost-benefit analysis, breakeven analysis, or make-or-buy analysis without some reasonably accurate method of estimating software costs and their sensitivity to various product, project, and environmental factors.

-Barry Boehm

This manual helps analysts and decision makers develop accurate, easy and quick software cost estimates for different operating environments such as ground, shipboard, air and space. It was developed by the Air Force Cost Analysis Agency (AFCAA) in conjunction with DoD Service Cost Agencies, and assisted by the University of Southern California and the Naval Postgraduate School. The intent is to improve quality and consistency of estimating methods across cost agencies and program offices through guidance, standardization, and knowledge sharing.

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2 Metrics Definitions

2.1 Size Measures

This chapter defines software product size measures used in Cost Estimating Relationship (CER) analysis. The definitions in this chapter should be compared to the commercial cost model definitions in the next chapter. This will help understand why estimates may vary between these analysis results in this manual and other model results.

For estimation and productivity analysis, it is necessary to have consistent measurement definitions. Consistent definitions must be used across models to permit meaningful distinctions and useful insights for project management.

2.2 Source Lines of Code (SLOC)

An accurate size estimate is the most important input to parametric cost models. However, determining size can be challenging. Projects may be composed of new code, code adapted from other sources with or without modifications, and automatically generated or translated code.

The common measure of software size used in this manual is Source Lines of Code (SLOC). SLOC are logical source statements consisting of data declarations and executables. Different types of SLOC counts will be discussed later.

2.2.1 SLOC Type Definitions

The core software size type definitions used throughout this manual are summarized in Table 1 below. These definitions apply to size estimation, data collection, and analysis. Some of the size terms have different interpretations in the different cost models as described in Chapter 3.

Table 1 Software Size Types

Size Type	Description
New	Original software created for the first time.
Adapted	Pre-existing software that is used as-is (Reused) or changed (Modified).
Reused	Pre-existing software that is not changed with the adaption parameter settings: Design Modification % (DM) = 0% Code Modification % (CM) = 0%
Modified	Pre-existing software that is modified for use by making design, code and / or test changes: Design Modification % (DM) >= 0% Code Modification % (CM) > 0%
Equivalent	A relative measure of the work done to produce software compared to the code-counted size of the delivered software. It adjusts the size of adapted software relative to developing it all new.

Table 1 Software Size Types

Size Type	Description
Generated	Software created with automated source code generators. The code to include for equivalent size consists of automated tool generated statements.
Converted	Software that is converted between languages using automated translators.
Commercial Off-The-Shelf Software (COTS)	Pre-built commercially available software components. The source code is not available to application developers. It is not included for equivalent size. Other unmodified software not included in equivalent size are Government Furnished Software (GFS), libraries, operating systems and utilities.

The size types are applied at the source code file level for the appropriate system-of-interest. If a component, or module, has just a few lines of code changed then the entire component is classified as Modified even though most of the lines remain unchanged. The total product size for the component will include all lines.

Open source software is handled, as with other categories of software, depending on the context of its usage. If it is not touched at all by the development team it can be treated as a form of COTS or reused code. However, when open source is modified it must be quantified with the adaptation parameters for modified code and be added to the equivalent size. The costs of integrating open source with other software components should be added into overall project costs.

2.2.2 SLOC Counting Rules

2.2.2.1 Logical Lines

The common measure of software size used in this manual and the cost models is Source Lines of Code (SLOC). SLOC are logical source statements consisting of data declarations and executables. Table 2 shows the SLOC definition inclusion rules for what to count. Based on the Software Engineering Institute (SEI) checklist method [Park 1992, Goethert et al. 1992], each checkmark in the "Includes" column identifies a particular statement type or attribute included in the definition, and vice-versa for the "Excludes".

Table 2 Equivalent SLOC Rules for Development

	Includes	Excludes
Statement Type		
Executable	✓	
Nonexecutable		
Declarations	✓	
Compiler directives	✓	
Comments and blank lines		✓
How Produced		
Programmed New	✓	
Reused	✓	
Modified	✓	
Generated		
Generator statements		✓
3GL generated statements	✓ (development)	✓ (maintenance)
Converted	✓	
Origin		
New	✓	
Adapted		
A previous version, build, or release	✓	
Unmodified COTS, GFS, library, operating system or utility		✓

Unfortunately, not all SLOC counts are reported using a logical count type. There are other SLOC count types. These are discussed next.

2.2.2.2 Physical Lines

The Physical SLOC count type is a count type where programming language terminators or delimiters are counted. This count type excludes blank lines in a source code file and includes everything else.

2.2.2.3 Total Lines

The Total SLOC count type includes a count of everything, including blank lines.

2.2.2.4 Non-Commented Source Statements (NCSS)

The Non-Commented Source Statement count type only counts lines containing a programming language source statement. No blank lines or comment-only lines are counted.

To prevent confusion in reporting measures of size and in storing results in databases, the type of SLOC count should always be recorded.

2.3 Equivalent Size

A key element in using software size for effort estimation is the concept of equivalent size. Equivalent size is a quantification of the effort required to use previously existing code along with new code. The challenge is normalizing the effort required to work on previously existing code to the effort required to create new code. For cost estimating relationships, the size of previously existing code does not require the same effort as the effort to develop new code.

The guidelines in this section will help the estimator in determining the total equivalent size. All of the models discussed in Chapter 3 have tools for doing this. However, for non-traditional size categories (e.g., a model may not provide inputs for auto-generated code), this manual will help the estimator calculate equivalent size outside of the tool and incorporate the size as part of the total equivalent size.

2.3.1 Definition and Purpose in Estimating

The size of reused and modified code is adjusted to be its equivalent in new code for use in estimation models. The adjusted code size is called Equivalent Source Lines of Code (ESLOC). The adjustment is based on the additional effort it takes to modify the code for inclusion in the product taking into account the amount of design, code and testing that was changed and is described in the next section.

In addition to newly developed software, adapted software that is modified and reused from another source and used in the product under development also contributes to the product's equivalent size. A method is used to make new and adapted code equivalent so they can be rolled up into an aggregate size estimate.

There are also different ways to produce software that complicate deriving ESLOC including generated and converted software. All of the categories are aggregated for equivalent size. A primary source for the equivalent sizing principles in this section is Chapter 9 of [Stutzke 2005].

For usual Third Generation Language (3GL) software such as C or Java, count the logical 3GL statements. For Model-Driven Development (MDD), Very High Level Languages (VHLL), or macro-based development, count the generated statements A summary of what to include or exclude in ESLOC for estimation purposes is in the table below.

Table 3 Equivalent SLOC Rules for Development

Source	Includes	Excludes
New	✓	
Reused	✓	
Modified	✓	
Generated		
Generator statements	✓	
3GL generated statements		✓
Converted		
COTS		✓
Volatility	✓	

2.3.2 Adapted SLOC Adjustment Factors

The AAF factor is applied to the size of the adapted software to get its equivalent size. The cost models have different weighting percentages as identified in the Chapter 3.

The normal Adaptation Adjustment Factor (AAF) is computed as:

Eq 1 $$AAF = (0.4 \times DM) + (0.3 \times CM) + (0.3 \times IM)$$

Where

% Design Modified (DM)

The percentage of the adapted software's design which is modified in order to adapt it to the new objectives and environment. This can be a measure of design elements changed such as UML descriptions.

% Code Modified (CM)

The percentage of the adapted software's code which is modified in order to adapt it to the new objectives and environment.

Code counting tools can be used to measure CM. See the chapter on the Unified Code Count tool in Appendix 9.2 for its capabilities, sample output and access to it.

% Integration Required (IM)

The percentage of effort required to integrate the adapted software into an overall product and to test the resulting product as compared to the normal amount of integration and test effort for software of comparable size.

Reused software has DM = CM = 0. IM is not applied to the total size of the reused software, but to the size of the other software directly interacting with it. It is frequently estimated using a percentage. *Modified* software has CM > 0.

2.3.3 Total Equivalent Size

Using the AAF to adjust Adapted Code size, the total equivalent size is:

Eq 2 *Total Equivalent Size = New Size + (AAF x Adapted Size)*

AAF assumes a linear effort relationship, but there can also be nonlinear effects. Data indicates that the AAF factor tends to underestimate modification effort [Selby 1988], [Boehm et al. 2001], [Stutzke 2005]. Two other factors used to account for these effects are Software Understanding and Programmer Unfamiliarity. These two factors and their usage are discussed in Appendix 9.2

2.3.4 Volatility

Volatility is requirements evolution and change, but not code thrown out. To account for the added effort, volatility is expressed as an additional percentage to size to obtain the total equivalent size for estimation.

Eq 3 *Total Equivalent Size = [New Size + (AAF x Adapted Size)] x (1 + Volitility)*

2.4 Development Effort

2.4.1 Activities and Lifecycle Phases

Software development involves much more activity than just coding. It includes the work involved in developing requirements, designs and tests. It involves documentation and reviews, configuration management, and quality assurance. It can be done using different life cycles (see discussion in Chapter 7.2.) and different ways of organizing the work (matrix, product lines, etc.). Using the DoD Software Resource Data Report as the basis, the following work activities/phases are included or excluded for effort.

Table 4 Effort Activities and Phases

Activity	Includes	Excludes
System Conceptualization		✓
Systems Requirements Development		✓
Software Requirements Analysis	✓	
Software Architecture and Detailed Design	✓	
Software Coding and Unit Test	✓	
Software Integration and System / Software Integration	✓	
Hardware / Software Integration and Test		✓
System Test and Evaluation		✓
Operational Test and Evaluation		✓
Production		✓

Phase	Includes	Excludes
Inception	✓	
Elaboration	✓	
Construction	✓	
Transition		✓

Software requirements analysis includes any prototyping activities. The excluded activities are normally supported by software personnel but are considered outside the scope of their responsibility for effort measurement. Systems Requirements Development includes equations engineering (for derived requirements) and allocation to hardware and software.

All these activities include the effort involved in documenting, reviewing and managing the work-in-process. These include any prototyping and the conduct of demonstrations during the development.

Transition to operations and operations and support activities are not addressed by these analyses for the following reasons:

- They are normally accomplished by different organizations or teams.
- They are separately funded using different categories of money within the DoD.
- The cost data collected by projects therefore does not include them within their scope.

From a life cycle point-of-view, the activities comprising the software life cycle are represented for new, adapted, reused, generated and COTS (Commercial Off-The-Shelf) developments. Reconciling the effort associated with the activities in the Work Breakdown Structure (WBS) across life cycle is necessary for valid comparisons to be made between results from cost models.

2.4.2 Labor Categories

The labor categories included or excluded from effort measurement is another source of variation. The categories consist of various functional job positions on a project. Most software projects have staff fulfilling the functions of:

- Project Managers
- Application Analysts
- Implementation Designers
- Programmers
- Testers
- Quality Assurance personnel
- Configuration Management personnel
- Librarians
- Database Administrators
- Documentation Specialists
- Training personnel
- Other support staff

Adding to the complexity of measuring what is included in effort data is that staff could be fulltime or part time and charge their hours as direct or indirect labor. The issue of capturing overtime is also a confounding factor in data capture.

2.4.3 Labor Hours

Labor hours (or Staff Hours) is the best form of measuring software development effort. This measure can be transformed into Labor Weeks, Labor Months and Labor Years. For modeling purposes, when weeks, months or years is required, choose a standard and use it consistently, e.g. 152 labor hours in a labor month.

If data is reported in units other than hours, additional information is required to ensure the data is normalized. Each reporting Organization may use different amounts of hours in defining a labor week, month or year. For whatever unit being reported, be sure to also record the Organization's definition for hours in a week, month or year. See [Goethert et a 1992] for a more detailed discussion.

2.5 Schedule

Schedule data are the start and end date for different development phases, such as those discuss in 2.4.1. Another important aspect of schedule data is entry or start and exit or completion criteria each phase. The criteria could vary between projects depending on its definition. As an example of exit or completion criteria, are the dates reported when:

- Internal reviews are complete
- Formal review with the customer is complete
- Sign-off by the customer
- All high-priority actions items are closed
- All action items are closed
- Products of the activity / phase are placed under configuration management
- Inspection of the products are signed-off by QA
- Management sign-off

An in-depth discussion is provided in [Goethert et al 1992].

3 Cost Estimation Models

In Chapter 2 metric definitions were discussed for sizing software, effort and schedule. Cost estimation models widely used on DoD projects are overviewed in this section. It describes the parametric software cost estimation model formulas (the one that have been published), size inputs, lifecycle phases, labor categories, and how they relate to the standard metrics definitions. The models include COCOMO, SEER-SEM, SLIM, and True S. The similarities and differences for the cost model inputs (size, cost factors) and outputs (phases, activities) are identified for comparison.

3.1 Effort Formula

Parametric cost models used in avionics, space, ground, and shipboard platforms by the services are generally based on the common effort formula shown below. Size of the software is provided in a number of available units, cost factors describe the overall environment and calibrations may take the form of coefficients adjusted for actual data or other types of factors that account for domain-specific attributes [Lum et al. 2001] [Madachy-Boehm 2008]. The total effort is calculated and then decomposed by phases or activities according to different schemes in the models.

Eq 4 $$Effort = A \times Size^{B} \times C$$

Where

- *Effort* is in person-months
- *A* is a calibrated constant
- *B* is a size scale factor
- *C* is an additional set of factors that influence effort.

The popular parametric cost models in widespread use today allow size to be expressed as lines of code, function points, object-oriented metrics and other measures. Each model has its own respective cost factors and multipliers for *EAF*, and each model specifies the B scale factor in slightly different ways (either directly or through other factors). Some models use project type or application domain to improve estimating accuracy. Others use alternative mathematical formulas to compute their estimates. A comparative analysis of the cost models is provided next, including their sizing, WBS phases and activities.

3.2 Cost Models

The models covered include COCOMO II, SEER-SEM, SLIM, and True S. They were selected because they are the most frequently used models for estimating DoD software effort, cost and schedule. A comparison of the COCOMO II, SEER-SEM and True S models for NASA projects is described in [Madachy-Boehm 2008]. A previous study at JPL analyzed the same three models with respect to some of their flight and ground projects [Lum et al. 2001]. The consensus of these studies is any of the models can be used effectively if it is calibrated properly. Each of the models has strengths and each has weaknesses. For this reason, the studies recommend using at least two models to estimate costs whenever it is possible to provide added assurance that you are within an acceptable range of variation.

Other industry cost models such as SLIM, Checkpoint and Estimacs have not been as frequently used for defense applications as they are more oriented towards business applications per [Madachy-Boehm 2008]. A previous comparative survey of software cost models can also be found in [Boehm et al. 2000b]. COCOMO II is a public domain model that USC continually updates and is implemented in several commercial tools. True S and SEER-SEM are both proprietary commercial tools with unique features but also share some aspects with COCOMO. All three have been extensively used and tailored for flight project domains. SLIM is another parametric tool that uses a different approach to effort and schedule estimation.

3.2.1 COCOMO II

The COCOMO (COnstructive COst MOdel) cost and schedule estimation model was originally published in 1981 [Boehm 1981]. COCOMO II research started in 1994, and the model continues to be updated at USC with the rest of the COCOMO model family. COCOMO II defined in [Boehm et al. 2000] has three submodels: Applications Composition, Early Design and Post-Architecture. They can be combined in various ways to deal with different software environments. The Application Composition model is used to estimate effort and schedule on projects typically done as rapid application development. The Early Design model involves the exploration of alternative system architectures and concepts of operation. This model is based on function points (or lines of code when available) and a set of five scale factors and seven effort multipliers.

The Post-Architecture model is used when top level design is complete and detailed information about the project is available and the software architecture is well defined. It uses Source Lines of Code and / or Function Points for the sizing parameter, adjusted for reuse and breakage; a set of 17 effort multipliers and a set of five scale factors that determine the economies / diseconomies of scale of the software under development. This model is the most frequent mode of estimation and used throughout this manual. The effort formula is:

Eq 5 $$PM = A \times Size^{B} \times \prod Em_{i}$$

Where

- *PM* is effort in person-months
- *A* is a constant derived from historical project data
- *Size* is in KSLOC (thousand source lines of code), or converted from other size measures
- *B* is an exponent for the diseconomy of scale dependent on additive scale drivers
- EM_i is an effort multiplier for the *i*th cost driver. The product of N multipliers is an overall effort adjustment factor to the nominal effort.

The COCOMO II effort is decomposed by lifecycle phase and activity as detailed in 3.3.2. More information on COCOMO can be found at http://csse.usc.edu/csse/research/COCOMOII/cocomo_main.html.

A web-based tool for the model is at http://csse.usc.edu/tools/COCOMO.

3.2.2 SEER-SEM

SEER-SEM is a product offered by Galorath, Inc. This model is based on the original Jensen model [Jensen 1983], and has been on the market over 15 years. The Jensen model derives from COCOMO and other models in its mathematical formulation. However, its parametric modeling equations are proprietary. Like True S, SEER-SEM estimates can be used as part of a composite modeling system for hardware / software systems. Descriptive material about the model can be found in [Galorath-Evans 2006].

The scope of the model covers all phases of the project lifecycle, from early specification through design, development, delivery and maintenance. It handles a variety of environmental and application configurations, and models different development methods and languages. Development modes covered include object oriented, reuse, COTS, spiral, waterfall, prototype and incremental development. Languages covered are 3rd and 4th generation languages (C++, FORTRAN, COBOL, Ada, etc.), as well as application generators.

The SEER-SEM cost model allows probability levels of estimates, constraints on staffing, effort or schedule, and it builds estimates upon a knowledge base of existing projects. Estimate outputs include effort, cost, schedule, staffing, and defects. Sensitivity analysis is also provided as is a risk analysis capability. Many sizing methods are available including lines of code and function points. For more information, see the Galorath Inc. website at http://www.galorath.com.

3.2.3 SLIM

The SLIM model is based on work done by Putnam [Putnam 1978] using the Norden / Rayleigh manpower distribution. The central part of Putnam's model, called the software equation, is [Putnam-Myers 1992]:

Eq 6 $$\textit{Product} = \textit{Productivity Parameter} \times (\textit{Effort}/B)^{1/3} \times \textit{Time}^{4/3}$$

Where

- *Product is* the new and modified software lines of code at delivery time
- *Productivity Parameter* is a process productivity factor
- *Effort* man years of work by all job classifications
- *B* is a special skills factor that is a function of size
- *Time* is lapsed calendar time in years

The Productivity Parameter, obtained from calibration, has values that fall in 36 quantized steps ranging from 754 to 3,524,578. The special skills factor, B, is a function of size in the range from 18,000 to 100,000 delivered SLOC that increases as the need for integration, testing, quality assurance, documentation and management skills grows.

The software equation can be rearranged to estimate total effort in man years:

Eq 7 $$\textit{Effort} = (\textit{Size} \times B^{1/3} / \textit{Productivity Parameter})^{3} \times (1/\textit{Time}^{4})$$

Putnam's model is used in the SLIM software tool based for cost estimation and manpower scheduling [QSM 2003].

3.2.4 True S

True S is the updated product to the PRICE S model offered by PRICE Systems. PRICE S was originally developed at RCA for use internally on software projects such as the Apollo moon program, and was then released in 1977 as a proprietary model. It fits into a composite modeling system and can be used to estimate more than just software costs. Many of the model's central algorithms were published in [Park 1988]. For more details on the model and the modeling system see the PRICE Systems website at http://www.pricesystems.com.

The PRICE S model consists of three submodels that enable estimating costs and schedules for the development and support of computer systems. The model covers business systems, communications, command and control, avionics, and space systems. PRICE S includes features for reengineering, code generation, spiral development, rapid development, rapid prototyping, object-oriented development, and software productivity measurement. Size inputs include SLOC, function points and / or Predictive Object Points (POPs). The True S system also provides a COCOMO II capability.

The True Planning estimation suite from PRICE Systems contains both the True S model and the COCOMO II cost model.

3.3 Model Comparisons

Comparisons between the models for the core metric definitions of size, activities and lifecycle phases follow.

3.3.1 Size Inputs

This section describes the major similarities and differences between the models related to software sizing. All models support size inputs for new and adapted software, and some support automatically translated or generated code. The models differ with respect to their detailed parameters for the developed categories of software per below.

Table 5 Comparison of Model Size Inputs

COCOMO II Size Inputs	SEER-SEM Size Inputs	True S Size Inputs
New Software		
New Size	New Size	New Size New Size Non-executable
Modified Software		
Adapted Size % Design Modified (DM) % Code Modified (CM) % Integration Required (IM) Assessment and Assimilation (AA) Software Understanding (SU) Programmer Unfamiliarity (UNFM)	Pre-exists Size [1] Deleted Size Redesign Required % Reimplementation Required % Retest Required %	Adapted Size Adapted Size Non-executable Amount of Modification % of Design Adapted % of Code Adapted % of Test Adapted Deleted Size Code Removal Complexity

Table 5 Comparison of Model Size Inputs

COCOMO II Size Inputs	SEER-SEM Size Inputs	True S Size Inputs
Reused Software		
Reused Size % Integration Required (IM) Assessment and Assimilation (AA)	Pre-exists Size [1, 2] Deleted Size Redesign Required % Reimplementation Required % Retest Required %	Reused Size [2] Reused Size Non-executable % of Design Adapted % of Code Adapted % of Test Adapted Deleted Size Code Removal Complexity
Generated Code		
		Auto Generated Code Size Auto Generated Size Non-executable
Automatically Translated		
Adapted SLOC Automatic Translation Productivity % of Code Reengineered		Auto Translated Code Size Auto Translated Size Non-executable
Deleted Code		
Volatility		
Requirements Evolution and Volatility (REVL)	Requirements Volatility (Change) [3]	

1 - Specified separately for Designed for Reuse and Not Designed for Reuse
2 - Reused is not consistent with AFCAA definition if DM or CM >0
3 - Not a size input but a multiplicative cost driver

The primary unit of software size in the effort models is Thousands of Source Lines of Code (KSLOC). KSLOC can be converted from other size measures, and additional size units can be used directly in the models as described next. User-defined proxy sizes can be developed for any of the models.

3.3.1.1 COCOMO II

The COCOMO II size model is based on SLOC or function points converted to SLOC, and can be calibrated and used with other software size units. Examples include use cases, use case points, object points, physical lines, and others. Alternative size measures can be converted to lines of code and used directly in the model or it can be independently calibrated directly to different measures.

3.3.1.2 SEER-SEM

Several sizing units can be used alone or in combination. SEER can use SLOC, function points and custom proxies. COTS elements are sized with *Features* and *Quick Size*. SEER allows proxies as a flexible way to estimate software size. Any countable artifact can be established as measure. Custom proxies can be used with other size measures in a project. Available pre-defined proxies that come with SEER include *Web Site Development*, *Mark II Function Point*, *Function Points* (for direct IFPUG-standard function points) and *Object-Oriented Sizing*.

SEER converts all size data into internal size units, also called effort units, Sizing in SEER-SEM can be based on function points, source lines of code, or user-defined metrics. Users can combine or select a single metric for any project element or for the entire project. COTS WBS elements also have specific size inputs defined either by Features, Object Sizing, or Quick Size, which describe the functionality being integrated.

New Lines of Code are the original lines created for the first time from scratch.

Pre-Existing software is that which is modified to fit into a new system. There are two categories of pre-existing software:

- Pre-existing, Designed for Reuse
- Pre-existing, Not Designed for Reuse.

Both categories of pre-existing code then have the following subcategories:

Pre-existing lines of code which is the number of lines from a previous system

Lines to be Deleted are those lines deleted from a previous system.

Redesign Required is the percentage of existing code that must be redesigned to meet new system requirements.

Reimplementation Required is the percentage of existing code that must be re-implemented, physically recoded, or reentered into the system, such as code that will be translated into another language.

Retest Required is the percentage of existing code that must be retested to ensure that it is functioning properly in the new system.

SEER then uses different proportional weights with these parameters in their AAF equation according to:

Eq 8 $$\text{Pre-existing Effective Size} = (0.4 \times A) + (0.25 \times B) + (0.3\ 5x\ C)$$

Where

- A is the percentages of code redesign
- B is the percentages of code reimplementation
- C is the percentages of code retest required

SEER also has the capability to take alternative size inputs:

Function-Point Based Sizing

- External Input (EI)
- External Output (EO)
- Internal Logical File (ILF)
- External Interface Files (EIF)
- External Inquiry (EQ)
- Internal Functions (IF) , any functions that are neither data nor transactions

Proxies

- Web Site Development
- Mark II Function Points
- Function Points (direct)
- Object-Oriented Sizing.

COTS Elements

- Quick Size
- Application Type Parameter
- Functionality Required Parameter
- Features
- Number of Features Used
- Unique Functions
- Data Tables Referenced
- Data Tables Configured

3.3.1.3 True S

The True S software cost model size measures may be expressed in different size units including Source Lines of Code (SLOC), function points, Predictive Object Points (POPs) or Use Case Conversion Points (UCCPs). True S also differentiates executable from non-executable software sizes. *Functional Size* describes software size in terms of the functional requirements that you expect a Software COTS component to satisfy. The True S software cost model size definitions for all of the size units are listed below.

- *Adapted Code Size*
  This describes the amount of existing code that must be changed, deleted, or adapted for use in the new software project. When the value is zero (0.00), the value for New Code Size or Reused Code Size must be greater than zero.
- *Adapted Size Non-executable*
  This value represents the percentage of the adapted code size that is non-executable (such as data statements, type declarations, and other non-procedural statements). Typical values for fourth generation languages range from 5.00 percent to 30.00 percent. When a value cannot be obtained by any other means, the suggested nominal value for non-executable code is 15.00 percent.

- *Amount for Modification*
  This represents the percent of the component functionality that you plan to modify, if any. The Amount for Modification value (like Glue Code Size) affects the effort calculated for the Software Design, Code and Unit Test, Perform Software Integration and Test, and Perform Software Qualification Test activities.
- *Auto Gen Size Non-executable*
  This value represents the percentage of the Auto Generated Code Size that is non-executable (such as, data statements, type declarations, and other non-procedural statements). Typical values for fourth generation languages range from 5.00 percent to 30.00 percent. If a value cannot be obtained by any other means, the suggested nominal value for non-executable code is 15.00 percent.
- *Auto Generated Code Size*
  This value describes the amount of code generated by an automated design tool for inclusion in this component.
- *Auto Trans Size Non-executable*
  This value represents the percentage of the Auto Translated Code Size that is non-executable (such as, data statements, type declarations, and other non-procedural statements). Typical values for fourth generation languages range from 5.00 percent to 30.00 percent. If a value cannot be obtained by any other means, the suggested nominal value for non-executable code is 15.00 percent.
- *Auto Translated Code Size*
  This value describes the amount of code translated from one programming language to another by using an automated translation tool (for inclusion in this component).
- *Auto Translation Tool Efficiency*
  This value represents the percentage of code translation that is actually accomplished by the tool. More efficient auto translation tools require more time to configure the tool to translate. Less efficient tools require more time for code and unit test on code that is not translated.
- *Code Removal Complexity*
  This value describes the difficulty of deleting code from the adapted code. Two things need to be considered when deleting code from an application or component: the amount of functionality being removed and how tightly or loosely this functionality is coupled with the rest of the system. Even if a large amount of functionality is being removed, if it is accessed through a single point rather than from many points, the complexity of the integration will be reduced.
- *Deleted Code Size*
  This describes the amount of pre-existing code that you plan to remove from the adapted code during the software project. The Deleted Code Size value represents code that is included in Adapted Code Size, therefore, it must be less than, or equal to, the Adapted Code Size value.

Equivalent Source Lines of Code

The ESLOC (Equivalent Source Lines of Code) value describes the magnitude of a selected cost object in Equivalent Source Lines of Code size units. True S does not use ESLOC in routine model calculations, but provides an ESLOC value for any selected cost object. Different organizations use different formulas to calculate ESLOC.

The True S calculation for ESLOC is:

Eq 9 $$\text{ESLOC} = \text{New Code} + (0.7 \times \text{Adapted Code}) + (0.1 \times \text{Reused Code})$$

To calculate ESLOC for a Software COTS, True S first converts Functional Size and Glue Code Size inputs to SLOC using a default set of conversion rates. New Code includes Glue Code Size and Functional Size when the value of Amount for Modification is greater than or equal to 25%. Adapted Code includes Functional Size when the value of Amount for Modification is less than 25% and greater than zero. Reused Code includes Functional Size when the value of Amount for Modification equals zero.

- *Functional Size*
  This value describes software size in terms of the functional requirements that you expect a Software COTS component to satisfy. When you select Functional Size as the unit of measure (Size Units value) to describe a Software COTS component, the Functional Size value represents a conceptual level size that is based on the functional categories of the software (such as Mathematical, Data Processing, or Operating System). A measure of Functional Size can also be specified using Source Lines of Code, Function Points, Predictive Object Points or Use Case Conversion Points if one of these is the Size Unit selected.
- *Glue Code Size*
  This value represents the amount of Glue Code that will be written. Glue Code holds the system together, provides interfaces between Software COTS components, interprets return codes, and translates data into the proper format. Also, Glue Code may be required to compensate for inadequacies or errors in the COTS component selected to deliver desired functionality.
- *New Code Size*
  This value describes the amount of entirely new code that does not reuse any design, code, or test artifacts. When the value is zero (0.00), the value must be greater than zero for Reused Code Size or Adapted Code Size.
- *New Size Non-executable*
  This value describes the percentage of the New Code Size that is non-executable (such as data statements, type declarations, and other non-procedural statements). Typical values for fourth generation languages range from 5.0 percent to 30.00 percent. If a value cannot be obtained by any other means, the suggested nominal value for non-executable code is 15.00 percent.
- *Percent of Code Adapted*
  This represents the percentage of the adapted code that must change to enable the adapted code to function and meet the software project requirements.

- *Percent of Design Adapted*
  This represents the percentage of the existing (adapted code) design that must change to enable the adapted code to function and meet the software project requirements. This value describes the planned redesign of adapted code. Redesign includes architectural design changes, detailed design changes, and any necessary reverse engineering.
- *Percent of Test Adapted*
  This represents the percentage of the adapted code test artifacts that must change. Test plans and other artifacts must change to ensure that software that contains adapted code meets the performance specifications of the Software Component cost object.
- *Reused Code Size*
  This value describes the amount of pre-existing, functional code that requires no design or implementation changes to function in the new software project. When the value is zero (0.00), the value must be greater than zero for New Code Size or Adapted Code Size.
- *Reused Size Non-executable*
  This value represents the percentage of the Reused Code Size that is non-executable (such as, data statements, type declarations, and other non-procedural statements). Typical values for fourth generation languages range from 5.00 percent to 30.00 percent. If a value cannot be obtained by any other means, the suggested nominal value for non-executable code is 15.00 percent.

3.3.1.4 SLIM

SLIM uses effective system size composed of new and modified code. Deleted code is not considered in the model. If there is reused code, then the Productivity Index (PI) factor may be adjusted to add in time and effort for regression testing and integration of the reused code.

SLIM provides different sizing techniques including:

- Sizing by history
- Total system mapping
- Sizing by decomposition
- Sizing by module
- Function point sizing.

Alternative sizes to SLOC such as use cases or requirements can be used in Total System Mapping. The user defines the method and quantitative mapping factor.

3.3.2 Lifecycles, Activities and Cost Categories

COCOMO II allows effort and schedule to be allocated to either a waterfall or MBASE lifecycle. MBASE is a modern iterative and incremental lifecycle model like the Rational Unified Process (RUP) or the Incremental Commitment Model (ICM). The phases include: (1) Inception, (2) Elaboration, (3) Construction, and (4) Transition.

True-S uses the nine DoD-STD-2167A development phases: (1) Concept, (2) System Requirements, (3) Software Requirements, (4) Preliminary Design, (5) Detailed Design, (6) Code / Unit Test, (7) Integration & Test, (8) Hardware / Software Integration, and (9) Field Test.

In SEER-SEM the standard lifecycle activities include: (1) System Concept, (2) System Requirements Design, (3) Software Requirements Analysis, (4) Preliminary Design, (5) Detailed Design, (6) Code and Unit Test, (7) Component Integration and Testing, (8) Program Test, (9) Systems Integration through OT&E & Installation, and (10) Operation Support. Activities may be defined differently across development organizations and mapped to SEER-SEMs designations.

In SLIM the lifecycle maps to four general phases of software development. The default phases are: 1) Concept Definition, 2) Requirements and Design, 3) Construct and Test, and 4) Perfective Maintenance. The phase names, activity descriptions and deliverables can be changed in SLIM. The “main build” phase initially computed by SLIM includes the detailed design through system test phases, but the model has the option to include the “requirements and design” phase, including software requirements and preliminary design, and a “feasibility study” phase to encompass system requirements and design.

The phases covered in the models are summarized in the Table 6.

Table 6 Lifecycle Phase Coverage

Model	Phases
COCOMO II	Inception Elaboration Construction Transition
SEER-SEM	System Concept System Requirements Design Software Requirements Analysis Preliminary Design Detailed Design Code / Unit Test Component Integration and Testing Program Test System Integration Through OT&E and Installation Operation Support
True S	Concept System Requirements Software Requirements Preliminary Design Detailed Design Code / Unit Test Integration and Test Hardware / Software Integration Field Test System Integration and Test Maintenance
SLIM	Concept Definition Requirements and Design Construction and Test Perfective Maintenance

The work activities estimated in the respective tools are in Table 7.

Table 7 Work Activities Coverage

Model	Activities
COCOMO II	Management Environment / CM Requirements Design Implementation Assessment Deployment
SEER-SEM	Management Software Requirements Design Code Data Programming Test CM QA
True S	Design Programming Data SEPGM QA CFM
SLIM	WBS Sub-elements of Phases: Concept Definition Requirements and Design Construct and Test Perfective Maintenance

The categories of labor covered in the estimation models and tools are listed in Table 8.

Table 8 Labor Activities Covered

Model	Categories
COCOMO II	Software Engineering Labor*
SEER-SEM	Software Engineering Labor* Purchases
True S	Software Engineering Labor* Purchased Good Purchased Service Other Cost
SLIM	Software Engineering Labor

* Project Management (including contracts), Analysts, Designers, Programmers, Testers, CM, QA, and Documentation

4 Software Resource Data Report (SRDR)

The Software Resources Data Report (SRDR) is used to obtain both the estimated and actual characteristics of new software developments or upgrades. Both the Government program office and, after contract award, the software contractor submit this report. For contractors, this report constitutes a contract data deliverable that formalizes the reporting of software metric and resource data. All contractors, developing or producing any software development element with a projected software effort greater than $20M (then year dollars) on major contracts and subcontracts within ACAT I and ACAT IA programs, regardless of contract type, must submit SRDRs. The data collection and reporting applies to developments and upgrades whether performed under a commercial contract or internally by a government Central Design Activity (CDA) under the terms of a Memorandum of Understanding (MOU).

4.1 DCARC Repository

The Defense Cost and Resource Center (DCARC), which is part of OSD Cost Assessment and Program Evaluation (CAPE), exists to collect Major Defense Acquisition Program (MDAP) cost and software resource data and make those data available to authorized Government analysts. Their website[1] is the authoritative source of information associated with the Cost and Software Data Reporting (CSDR) system, including but not limited to: policy and guidance, training materials, and data. CSDRs are DoD's only systematic mechanism for capturing completed development and production contract "actuals" that provide the right visibility and consistency needed to develop credible cost estimates. Since credible cost estimates enable realistic budgets, executable contracts and program stability, CSDRs are an invaluable resource to the DoD cost analysis community and the entire DoD acquisition community.

The Defense Cost and Resource Center (DCARC), was established in 1998 to assist in the re-engineering of the CSRD process. The DCARC is part of OSD Cost Assessment and Program Evaluation (CAPE). The primary role of the DCARC is to collect current and historical Major Defense Acquisition Program cost and software resource data in a joint service environment and make those data available for use by authorized government analysts to estimate the cost of ongoing and future government programs, particularly DoD weapon systems.

The DCARC's Defense Automated Cost Information Management System (DACIMS) is the database for access to current and historical cost and software resource data needed to develop independent, substantiated estimates. DACIMS is a secure website that allows DoD government cost estimators and analysts to browse through almost 30,000 CCDRs, SRDR and associated documents via the Internet. It is the largest repository of DoD cost information.

[1] http://dcarc.cape.osd.mil/CSDR/CSDROverview.aspx

4.2 SRDR Reporting Frequency

The SRDR Final Developer Report contains measurement data as described in the contractor's SRDR Data Dictionary. The data reflects the scope relevant to the reporting event, Table 9. Both estimates (DD Form 2630-1,2) and actual results (DD Form 2630-3) of software (SW) development efforts are reported for new or upgrade projects.

- SRDR submissions for contract complete event shall reflect the entire software development project.
- When the development project is divided into multiple product builds, each representing production level software delivered to the government, the submission should reflect each product build.
- SRDR submissions for completion of a product build shall reflect size, effort, and schedule of that product build.

Table 9 SRDR Reporting Events

Event	Report Due	Who Provides	Scope of Report
Pre-Contract (180 days prior to award)	Initial	Government Program Office	Estimates of the entire completed project. Measures should reflect cumulative grand totals.
Contract award	Initial	Contractor	Estimates of the entire project at the level of detail agreed upon. Measures should reflect cumulative grand totals.
At start of each build	Initial	Contractor	Estimates for completion for the build only.
Estimates corrections	Initial	Contractor	Corrections to the submitted estimates.
At end of each build	Final	Contractor	Actuals for the build only.
Contract completion	Final	Contractor	Actuals for the entire project. Measures should reflect cumulative grand totals.
Actuals corrections	Final	Contractor	Corrections to the submitted actuals.

Perhaps it is not readily apparent how important it is to understand the submission criteria. SRDR records are a mixture of complete contracts and individual builds within a contract. And there are initial and final reports along with corrections. Mixing contract data and build data or mixing initial and final results or not using the latest corrected version **will produce inconclusive, if not incorrect, results**.

The report consists of two pages, see Chapter 9.4. The fields in each page are listed below.

4.3 SRDR Content

4.3.1 Administrative Information (SRDR Section 3.1)

- Security Classification
- Major Program
    - Program Name
    - Phase / Milestone
    - Reporting Organization Type (Prime, Subcontractor, Government)
- Name / Address
    - Reporting Organization
    - Division
- Approved Plan Number
- Customer (Direct-Reporting Subcontractor Use Only)
- Contract Type
- WBS Element Code
- WBS Reporting Element
- Type Action
    - Contract No
    - Latest Modification
    - Solicitation No
    - Common Reference Name
    - Task Order / Delivery Order / Lot No
- Period of Performance
    - Start Date (YYYYMMDD)
    - End Date (YYYYMMDD)
- Appropriation (RDT&E, Procurement, O&M)
- Submission Number
- Resubmission Number
- Report As Of (YYYYMMDD)
- Date Prepared (YYYYMMDD)
- Point of Contact
    - Name (Last, First, Middle Initial)
    - Department
    - Telephone Number (include Area Code)
    - Email
    - Development Organization
- Software Process Maturity
- Lead Evaluator
- Certification Date

- Evaluator Affiliation
- Precedents (List up to five similar systems by the same organization or team.)
- SRDR Data Dictionary Filename
- Comments (on Report Context and Development Organization)

4.3.2 Product and Development Description (SRDR Section 3.2)

- Functional Description. A brief description of its function.
- Software Development Characterization
- Application Type
  - Primary and Secondary Programming Language.
  - Percent of Overall Product Size. Approximate percentage (up to 100%) of the product size that is of this application type.
  - Actual Development Process. Enter the name of the development process followed for the development of the system.
  - Software Development Method(s). Identify the software development method or methods used to design and develop the software product .
  - Upgrade or New Development. Indicate whether the primary development was new software or an upgrade.
  - Software Reuse. Identify by name and briefly describe software products reused from prior development efforts (e.g. source code, software designs, requirements documentation, etc.).
- COTS / GOTS Applications Used.
  - Name. List the names of the applications or products that constitute part of the final delivered product, whether they are COTS, GOTS, or open-source products.
  - Integration Effort (Optional). If requested by the CWIPT, the SRD report shall contain the actual effort required to integrate each COTS / GOTS application identified in Section 3.2.4.1.
- Staffing.
  - Peak Staff. The actual peak team size, measured in full-time equivalent (FTE) staff.
  - Peak Staff Date. Enter the date when the actual peak staffing occurred.
  - Hours per Staff-Month. Enter the number of direct labor hours per staff-month.
- Personnel Experience in Domain. Stratify the project staff domain experience by experience level and specify the percentage of project staff at each experience level identified. Sample Format 3 identifies five levels:
  - Very Highly Experienced (12 or more years)
  - Highly Experienced (6 to 12 years)
  - Nominally Experienced (3 to 6 years)
  - Low Experience (1 to 3 years)
  - Inexperienced / Entry Level (less than a year)

4.3.3 Product Size Reporting (SRDR Section 3.3)

- Number of Software Requirements. Provide the actual number of software requirements.
    - Total Requirements. Enter the actual number of total requirements satisfied by the developed software product at the completion of the increment or project.
    - New Requirements. Of the total actual number of requirements reported, identify how many are new requirements.
- Number of External Interface Requirements. Provide the number of external interface requirements, as specified below, not under project control that the developed system satisfies.
    - Total External Interface Requirements. Enter the actual number of total external interface requirements satisfied by the developed software product at the completion of the increment or project.
    - New External Interface Requirements. Of the total number of external interface requirements reported, identify how many are new external interface requirements.
- Requirements Volatility. Indicate the amount of requirements volatility encountered during development as a percentage of requirements that changed since the Software Requirements Review.
- Software Size.
    - Delivered Size. Capture the delivered size of the product developed, not including any code that was needed to assist development but was not delivered (such as temporary stubs, test scaffoldings, or debug statements). Additionally, the code shall be partitioned (exhaustive with no overlaps) into appropriate development categories. A common set of software development categories is new, reused with modification, reused without modification, carry-over code, deleted code, and auto-generated code.
        - Reused Code With Modification. When code is included that was reused with modification, provide an assessment of the amount of redesign, recode, and retest required to implement the modified or reused code.
        - Reuse Code Without Modification. Code reused without modification is code that has no design or code modifications. However, there may be an amount of retest required. Percentage of retest should be reported with the retest factors described above.
        - Carryover Code. Report shall distinguish between code developed in previous increments that is carried forward into the current increment and code added as part of the effort on the current increment.
        - Deleted Code. Include the amount of delivered code that was created and subsequently deleted from the final delivered code.
        - Auto-generated Code. If the developed software contains auto-generated source code, report an auto-generated code sizing partition as part of the set of development categories.
        - Subcontractor-Developed Code.

- Counting Convention. Identify the counting convention used to count software size.
- Size Reporting by Programming Language (Optional).
- Standardized Code Counting (Optional). If requested, the contractor shall use a publicly available and documented code counting tool, such as the University of Southern California Code Count tool, to obtain a set of standardized code counts that reflect logical size. These results shall be used to report software sizing.

4.3.4 Resource and Schedule Reporting (SRDR Section 3.4)

The Final Developer Report shall contain actual schedules and actual total effort for each software development activity.

- Effort. The units of measure for software development effort shall be reported in staff-hours. Effort shall be partitioned into discrete software development activities.
- WBS Mapping.
- Subcontractor Development Effort. The effort data in the SRD report shall be separated into a minimum of two discrete categories and reported separately: Prime Contractor Only and All Other Subcontractors.
- Schedule. For each software development activity reported, provide the actual start and end dates for that activity.

4.3.5 Product Quality Reporting (SRDR Section 3.5 - Optional)

Quality should be quantified operationally (through failure rate and defect discovery rate). However, other methods may be used if appropriately explained in the associated SRDR Data Dictionary.

- Number of Defects Discovered. Report an estimated number of defects discovered during integration and qualification testing. If available, list the expected defect discovery counts by priority, e.g. 1, 2, 3, 4, 5. Provide a description of the priority levels if used.
- Number of Defects Removed. Report an estimated number of defects removed during integration and qualification testing. If available, list the defect removal counts by priority.

4.3.6 Data Dictionary

The SRDR Data Dictionary contains, at a minimum, the following information in addition to the specific requirements identified in Sections 3.1 through 3.5:

- Experience Levels. Provide the contractor's specific definition (i.e., the number of years of experience) for personnel experience levels reported in the SRD report.
- Software Size Definitions. Provide the contractor's specific internal rules used to count software code size.
- Software Size Categories. For each software size category identified (i.e., New, Modified, Unmodified, etc.), provide the contractor's specific rules and / or tools used for classifying code into each category.
- Peak Staffing. Provide a definition that describes what activities were included in peak staffing.
- Requirements Count (Internal). Provide the contractor's specific rules and / or tools used to count requirements.
- Requirements Count (External). Provide the contractor's specific rules and / or tools used to count external interface requirements.
- Requirements Volatility. Provide the contractor's internal definitions used for classifying requirements volatility.
- Software Development Activities. Provide the contractor's internal definitions of labor categories and activities included in the SRD report's software activity.
- Product Quality Reporting. Provide the contractor's internal definitions for product quality metrics being reported and specific rules and / or tools used to count the metrics.

5 Data Assessment and Processing

This chapter discusses transforming the SRDR data into useful information for use in creating Cost Estimating Relationships (CER) and to provide productivity benchmarks for use in management oversight.

The Software Resources Data Report (SRDR) has data quality issues not uncommon with other datasets. This presents many challenges when attempting to create CERs and productivity benchmarks. The list below shows the challenges when working with this data:

- Inadequate information on modified code (only size provided)
- Inadequate information on size change or growth
- Size measured inconsistently
- Inadequate information on average staffing or peak staffing
- Inadequate information on personnel experience
- Inaccurate effort data in multi-build components
- Missing effort data
- Replicated duration (start and end dates) across components
- Inadequate information on schedule compression
- Missing schedule data
- No quality data

The remedy for some of these challenges is to find a way to normalize the data to the definitions discussed in Chapter 2. Other techniques are required to fill in missing data, either by consulting other sources or using statistical techniques to fill in missing values in a table. What is needed is a process to make the data usable.

5.1 Workflow

The data assessment and processing workflow has six steps. This workflow was used in the analysis of the SRDR data. Each of these steps is described in detail.

1. Gather the data that has been collected.
2. Review and inspect each data point.
3. Determine a quantitative quality level based on the data inspection.
4. Correct missing or questionable data. There were several things that can be done about this. Data that cannot be repaired is excluded from the analysis.
5. The data has to be normalized to a common unit of measure or scope of what is covered by the data.
6. Finally the data is segmented by Operating Environment and Software Domain.

5.1.1 Gather Collected Data

Historical data is stored in a variety of formats. Often there is data in a record that is not relevant for cost estimation analysis. All too often, there is not enough data to support a thorough analysis.

The data has to be transformed from different formats into a common data format that supports the analysis objectives. A common data format for cost estimation analysis would be different for analysis of requirements growth, defect discovery / removal or process improvement return on investment to name a few.

The common data format for cost estimation analysis requires detail information on:

- Amount of workload (expressed as a functional measure or a product measure)
- Development and support effort
- Project or build duration

Additional contextual data is needed to provide information on what the data represents, e.g.,

- Organization that developed the software
- What the application does
- Where the software fits into the system (is it all of the software, a build, a configuration item, or a small software unit)

The common data format used in analyzing SRDR data had additional information than was found in the SRDR report.

5.1.2 Inspect each Data Point

As the gathered data is being transformed into the common data format, inspect the data for completeness, integrity, and "reasonable-ness". The first activity is to examine the project context information.

Project Context

- Are all of the data available to fill the common data format fields?
- How would this software component be characterized?
    - What does this component do?
    - Were there any extenuating circumstances concerning development, e.g. management change, large requirements change, stop / restart work?
    - Is the Data Dictionary for that record available as a standalone file?
    - Is there any additional information that can be consulted about the data during analysis, such as:
        - Acquisition Strategy
        - Acquisition Support Plan (ASP)
        - Contract Plan
        - Cost Analysis Requirements Document (CARD)
        - Capability Description Document (CDD)
        - Software Requirements Specification (SRS)
        - Work Breakdown Structure (WBS)
        - Earned Value Management System data (EVMS)

Next, the size, effort, schedule and productivity data are examined.

Size Data

- Does the size data look sound?
    - Is the size part of multi-build release?
    - Was all code auto-generated?
    - Was code rewritten after AG?
    - Was a portion of a legacy system included in the sizing data?
        - How much software was adapted (modified)?
        - How much software was reused (no changes)?
- Is there effort and schedule data for each software activity?
- Is there repeating size data?

Effort Data

- What labor was included in the reported hours?
    - Engineering labor
    - Management labor
    - Support labor: CM, QA, Process Improvement, Safety, Security, Dev. Environment support
- What labor was reported in the "Other" activity?
    - Was Requirements effort reported for all builds?
    - Were there continuous integration activities across all builds?

Schedule Data

- Was there schedule compression mentioned on the project
- Were there parallel multiple builds (same start & end date)

Productivity Screening

- Is a quick productivity check reasonably close to software with similar functionality?
    - Is this record an outlier in a scatter plot with other similar data?

5.1.3 Determine Data Quality Levels

From the inspection process, assign the record a data quality rating. The criteria in Table 10 can be used to determine rating values.

Table 10 Data Quality Rating Scale

Attribute	Value	Condition
Size:	1.0	if size data present
	0	if no size data
Size Count Type: (providing size data is present)	1.0	if size is Logical SLOC
	0.7	if size is Non-Commented Source Statements
	0.5	if size is Physical Lines (Comment and Source Statements)
	0.4	if size is Total Lines (all lines in file: blank, comment, source)
	0	if no size data
ESLOC Parameters:	1.0	if modification parameters provided for Auto-gen, Modified & Reuse
	0.5	if New SLOC and no size data for Auto-gen, Modified or Reuse
	0	if no modification parameters provided for either Modified, Auto-gen, or Reused SLOC counts
CSCI-level Data:	1.0	if Total Size is 5,000 < Size < 250,000
	0	if Total Size < 5,000 or Size > 250,000
Effort:	1.0	if effort reported for all phases
	0.5	if effort is reported as a total
	0	if effort is missing for a phase
Schedule:	1.0	if duration reported for all phases
	0.5	if duration is reported as a total
	0	is duration is missing for a phase
Productivity:	1.0	if record is in the expected value range
	0.5	if record is within 1 standard deviation from the mean
	0	if record is a clear outlier

As each record is rated by the criteria above, an overall quality level is assigned by:

Eq 10 $$\text{Quality Level} = (\text{Size} + \text{Size Count Type} + \text{ESLOC Parameters} + \text{CSCI level} + \text{Effort} + \text{Schedule} + \text{Productivity}) / 7$$

The quality level is a quick indicator of the degree of issues found in the record. As the recorded is corrected through supplemental information, the rating is revised. Because the range of the quality level scale is between 0 and 1.0, it could be used as a *weight* during analysis.

5.1.4 Correct Missing or Questionable Data

The quality level makes clear which records need additional work. There are several approaches available to resolving missing or questionable data. These are listed in a recommended order:

1. Consult the accompanying Data Dictionary discussed in Chapter 4.3.6
2. Consult any supplemental on the project that is available, e.g., ASP, CARD, CDD, EVMS, SRS, WBS, etc.
3. Scheduling follow-up meetings with SRDR data contributor. Data quality issues that were fixed in the past by the SRDR contributor:

   - Revised missing size, effort and duration data
   - Obtained Adaptation Adjustment Factor (AAF) parameters
   - Confirmed productivity type and environment
   - Confirmed CSCI-level of reporting
   - Asked about problems with - high / low, long / short - size, effort and duration data

As a result of inspecting the data and attempting to correct the issues found, no "bad" data or “outliers” are excluded from the analysis on arbitrary grounds. However, data issues that cannot be resolved are excluded from analysis.

5.1.5 Normalize Size and Effort Data

Normalizing data is making a type of data the same. For example, if SLOC was measured by different criteria, all SLOC counts are converted into a common count method. If effort data covers different lifecycle phases, all effort data is converted to cover the same phases. Normalization reduces noise in the data. Otherwise, it will pose a significant threat to statistical validity.

5.1.5.1 Converting to Logical SLOC

With the SRDR data, the SLOC were counted using different methods.

- Total Count: a line in a file, e.g. carriage returns including blanks and comment lines
- Non-Commented Source Statements (NCSS) Count: a line in a file that is not a blank or comment line
- Logical Count: as defined earlier in Chapter 2.2.2.1

For analysis, the definition of a source line of code needs to be as consistent as possible to eliminate noise in the data. A logical source line of code has been selected as the baseline SLOC definition.

If a source line of code count was defined as either Total or NCSS, these counts were converted to a Logical SLOC count. An experiment was run using the UCC tool, described in Appendix 9.2, on public domain software applications and additional contributions from USC-CSSE Affiliates. Total, NCSS and Logical counts were taken from the program files. Six programming languages were sampled:

- Ada
- C#
- C/C++
- Java
- PERL
- PHP

The total number of data points was 40. The results of this experiment are described next.

NCSS Line Count Conversion to Logical

The size counts for NCSS and Logical were analyzed for their relationship. Two analyses were conducted, one for all of the size data and another for the lower 80% of the size data. The two relationships are expressed as follows (the intercept was constrained to zero[2]):

Eq 11 *All Sizes: Logical SLOC count = 0.44 x NCSS count*

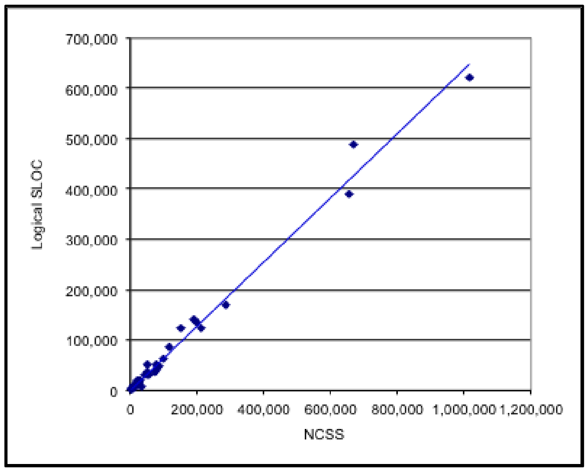
Eq 12 *Lower 80%: Logical SLOC count = 0.66 x NCSS count*

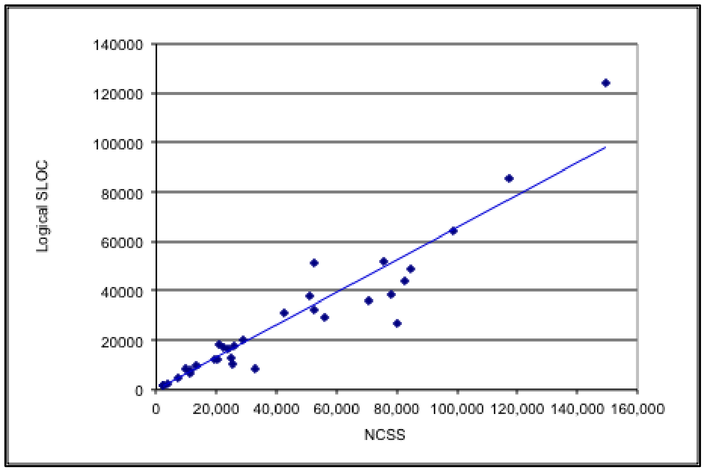
The statistics for these relationships are in Table 11 and a scatter plot in Figure 1.

Table 11 NCSS-Logical Relationship Statistics

Statistics	All Sizes	Lower 80%
Coefficient	0.44	0.66
Total number of observations	40	32
Min - Max Range (KSLOC)	2.3 – 1,690	2.3 – 149
Adjusted R^2	0.86	0.95
Standard Error	0.03	0.03
Lower 95% Confidence Interval	0.38	0.60
Upper 95% Confidence Interval	0.55	0.71
T-Statistic	15.35	23.73

[2] When modeling this relationship, an overhead amount (as represented by an intercept value) does not make sense, i.e., there is no overhead if there are zero lines to be converted. Incidentally, when the regression was run on all sizes without the zero constraint, the constant had a T-statistic of 1.90 and a P-level of 0.70.





All Counts Lower 80% of Counts

Figure 1 NCSS to Logical SLOC Plot

Total Line Count Conversion to Logical

As with NCSS counts, counts for NCSS and Logical were analyzed for their relationship. Two analyses were conducted, one for all of the size data and another for the lower 80% of the size data. The two relationships are expressed as follows (the intercept was constrained to zero):

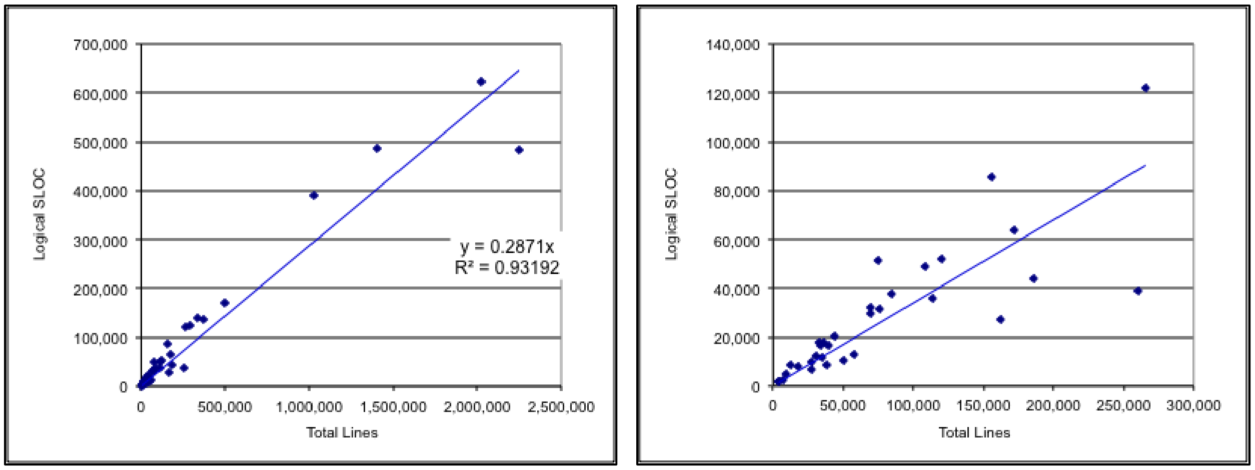
Eq 13 *All Sizes: Logical SLOC count = 0.29 x Total count*

Eq 14 *Lower 80%: Logical SLOC count = 0.34 x Total count*

The statistics for these relationships are in Table 12 and a scatter plot in Figure 2.

Table 12 Total-Logical Relationship Statistics

Statistics	All Sizes	Lower 80%
Coefficient	0.29	0.34
Total number of observations	40	32
Min - Max Range (KSLOC)	3.5 – 2,249	3.5 – 265
Adjusted R^2	0.95	0.85
Standard Error	0.01	0.03
Lower 90% Confidence Interval	0.27	0.29
Upper 90% Confidence Interval	0.31	0.39
T-Statistic	27.12	13.00



All Counts

Lower 80% of Counts

Figure 2 Total to Logical SLOC Plot

Conclusion

The 80% solution was used in this analysis. The 80% conversion factors appear to be more "reasonable" than the 100% factors. A future version of this manual will explore the relationships for NCSS and Total counts to Logical counts for each of the six programming languages.

5.1.5.2 Convert Raw SLOC into Equivalent SLOC

Equivalent Size is a method used to make new and adapted code equivalent so they can be rolled up into an aggregate size estimate (discussed in Chapter 2.3.2). This adjustment is called Equivalent Source Lines of Code (ESLOC):

Eq 15

$$\begin{aligned} ESLOC = {} & \text{New SLOC} + \\ & (AAF_M \times \text{Modified SLOC}) + \\ & (AAF_R \times \text{Reused SLOC}) + \\ & (AAF_{AG} \times \text{Auto-Generated SLOC}) \end{aligned}$$

Where: $AAF_i = (0.4 \times DM) + (0.3 \times CM) + (0.3 \times IM)$

The SRDR data did not include the parameters for DM, CM and IM. Independent data collection of similar data was conducted. Based on the data collected and the grouping of the data by Operating Environment (Chapter 5.2.1) and Productivity Types (Chapter 5.2.2), guidelines for filling-in missing data were derived from that data that had the adaptation parameters, Table 13.

As shown in the equation above, there are four types of code: New, Auto-Generated, Reused, and Modified (see Chapter 2.2.1). The DM, CM and IM parameters are not required for each type.

- New code does not require any adaption parameters. Nothing has been modified.

- Auto-Generated code does not require the DM or CM adaption parameters. However, it does require testing, IM. If Auto-Generated code does require modification, then it becomes Modified code and the adaptation factors for Modified code apply.
- Reuse code does not require the DM or CM adaption parameters either. It also requires testing, IM. If Reused code does require modification, then it becomes Modified code and the adaptation factors for Modified code apply.
- Modified code requires the three parameters, DM, CM and IM, representing modifications to the modified code design, code and integration testing.

Table 13 shows DM, CM and IM for different productivity types. The table shows the code type, number of records used to derive the adaptation parameters, the mean value of the parameter with its 95% confidence interval, and the mean value. The adaptation adjustment factor (AAF) is shown in the last column. This factor is the portion of adapted code that will be used for equivalent SLOC. Unfortunately there was not enough data to support reporting for all productivity types.

Table 13 Adapted Code Parameters

			DM		CM		IM		
PT	Code Type	#	Mean	M	Mean	M	Mean	M	AAF
	Auto-Gen	0					0.00 ± 0.00	0.00	0.00
SCP	Reused	18					0.51 ± 0.21	0.42	0.15
	Modified	7	0.26 ± 0.22	0.25	0.33 ± 0.20	0.50	0.66 ± 0.40	1.00	0.40
	Auto-Gen	0					0.00 ± 0.00	0.00	0.00
RTE	Reused	8					0.17 ± 0.23	0.10	0.05
	Modified	14	0.13 ± 0.10	0.05	0.30 ± 0.19	0.10	0.95 ± 0.07	1.00	0.85
	Auto-Gen	1					0.13 ± 0.00	0.13	0.04
MP	Reused	12					0.36 ± 0.20	0.33	0.11
	Modified	21	0.75 ± 0.12	1.00	0.89 ± 0.12	1.00	0.95 ± 0.07	1.00	0.85
	Auto-Gen	12					0.37 ± 0.25	0.13	0.11
SYS	Reused	6					0.56 ± 0.40	0.50	0.17
	Modified	14	0.22 ± 0.19	0.03	0.34 ± 0.20	0.17	0.68 ± 0.18	0.58	0.39
	Auto-Gen	7					0.12 ± 0.20	0.10	0.04
SCI	Reused	15					0.46 ± 0.20	0.33	0.14
	Modified	10	0.34 ± 0.30	0.17	0.53 ± 0.30	0.41	0.78 ± 0.18	0.88	0.53
	Auto-Gen	2					0.33 ± 0.00	0.33	0.10
IIS	Reused	7					0.45 ± 0.24	0.33	0.14
	Modified	4	1.00 ± 0.00	1.00	0.81 ± 0.60	1.00	0.90 ± 0.32	1.00	0.91

General observations and usage guidelines are:

- The more real-time nature of the software, the less the design is modified, i.e. Intel and Information Systems (IIS) have a DM of 100% whereas Sensor Control and Signal Processing (SCP) have a DM of 26%.
- The same is generally true for CM. The real-time nature appears to influence how much code is modified.

- IM is usually higher than either DM or CM. It the software being estimated requires more reliability or is more complex, a higher value for IM should be used.

While the mean value is provided for DM, CM and IM, compare the mean to the median. This is an indication of skewing in the data. This should also influence your decision on which values to choose within the 95% confidence interval.

A future version of this manual will process more data and expand the adapted code parameter table to additional productivity types. It will also analyze these parameters across operating environments.

5.1.5.3 Adjust for Missing Effort Data

Guidelines for adjusting for missing effort data are shown in Table 14. As these were developed, consideration was given to the productivity type (PT). Average Effort percentages were derived for each Productivity Type using the analysis dataset (~300 records). Any missing effort data was adjusted using the appropriate effort percentage and productivity type. Data missing more than two phases of effort were not used in the analysis. This analysis is based on research by [Tan 2012].

Table 14 Average Activity Effort Percentages Based On Complete Data

Productivity Type	Requirement	Arch & Design	Code & Unit Test	Integration & QT
IIS	11.56%	27.82%	35.63%	24.99%
MP	20.56%	15.75%	28.89%	34.80%
PLN	16.22%	12.27%	50.78%	20.73%
RTE	15.47%	26.65%	26.71%	31.17%
SCI	7.38%	39.90%	32.05%	20.67%
SSP	10.80%	45.20%	20.34%	23.66%
SYS	17.61%	21.10%	28.75%	32.54%
VC	18.47%	23.60%	31.32%	26.61%

A future version of this manual will process more data and expand the average effort percentages table to additional productivity types. Additionally, analysis of schedule duration for the different activities will be conducted.

5.2 Data Segmentation

Data segmentation can be challenging because Cost and Schedule Estimating Relationships (CER and SER) are different for different types of software. Factors such as application complexity; impact of loss due to reliability; autonomous modes of operation; constraints on timing, storage, and power; security requirements; and complex interfaces influence the cost and time to develop applications. Parametric cost models have a number of adjustable parameters that attempt to account for these factors. Many of these parameters, however, are unknown until contract award.

Instead of developing CERs and SERs with many parameters, the approach taken by this project is based on grouping similar software applications together. These groups are called Application Domains. Application Domains implement a combination of hardware and software components to achieve the intended functionality. However, because Application Domains then to represent an entire subsystem, e.g. Communications, the approach taken was to use a generic description of software domains called productivity types (PT). The operating environment for each PT is considered as well. Both the operating environment and domain are considered in this analysis to produce the productivity types.

5.2.1 Operating Environments (OpEnv)

Operating Environments have similar systems, similar products, similar operational characteristics, and similar requirements:

- High-speed vehicle versus stationary
- Battery operated versus ground power
- Unrecoverable platform versus readily accessible
- Limited, non-upgradeable computing processor capacity versus racks of processors
- Fixed internal and external memory capacity versus expandable capacity

There are 11 operating environments:

Table 15 Operating Environments

Operating Environment (OpEnv)		Examples
Ground Site (GS)	Fixed (GSF)	Command Post, Ground Operations Center, Ground Terminal, Test Faculties
	Mobile (GSM)	Intelligence gathering stations mounted on vehicles, Mobile missile launcher
Ground Vehicle (GV)	Manned (GVM)	Tanks, Howitzers, Personnel carrier
	Unmanned (GVU)	Robotic vehicles
Maritime Vessel (MV)	Manned (MVM)	Aircraft carriers, destroyers, supply ships, submarines
	Unmanned (MVU)	Mine hunting systems, Towed sonar array
Aerial Vehicle (AV)	Manned (AVM)	Fixed-wing aircraft, Helicopters
	Unmanned (AVU)	Remotely piloted air vehicles
Space Vehicle (SV)	Manned (SVM)	Passenger vehicle, Cargo vehicle, Space station
	Unmanned (SVU)	Orbiting satellites (weather, communications), Exploratory space vehicles
Ordinance Vehicle (OV)	Unmanned (OVU)	Air-to-air missiles, Air-to-ground missiles, Smart bombs, Strategic missiles

The operating environments can be aggregated into six high-level environments. This is useful when there is not enough data for each of the 11 environments in Table 15:

1. Ground Site (GS)
2. Ground Vehicle (GV)
3. Maritime Vessel (MV)
4. Aerial Vehicle (AV)
5. Space Vehicle (SV)
6. Ordinance Vehicle (OV)

5.2.2 Productivity Types (PT)

Productivity types are groups of application productivities that are characterized by the following:

- Required software reliability
- Database size - if there is a large data processing and storage component to the software application
- Product complexity
- Integration complexity
- Real-time operating requirements
- Platform volatility, Target system volatility
- Special display requirements
- Development re-hosting
- Quality assurance requirements
- Security requirements
- Assurance requirements
- Required testing level

There are 14 productivity types:

Table 16 Productivity Types

PT	Description
Sensor Control and Signal Processing (SCP)	Software that requires timing-dependent device coding to enhance, transform, filter, convert, or compress data signals. Ex.: Beam steering controller, sensor receiver / transmitter control, sensor signal processing, sensor receiver / transmitter test. Ex. of sensors: antennas, lasers, radar, sonar, acoustic, electromagnetic.
Vehicle Control (VC)	Hardware & software necessary for the control of vehicle primary and secondary mechanical devices and surfaces. Ex: Digital Flight Control, Operational Flight Programs, Fly-By-Wire Flight Control System, Flight Software, Executive.
Vehicle Payload (VP)	Hardware & software which controls and monitors vehicle payloads and provides communications to other vehicle subsystems and payloads. Ex: Weapons delivery and control, Fire Control, Airborne Electronic Attack subsystem controller, Stores and Self-Defense program, Mine Warfare Mission Package.
Real Time Embedded (RTE)	Real-time data processing unit responsible for directing and processing sensor input / output. Ex: Devices such as Radio, Navigation, Guidance, Identification, Communication, Controls And Displays, Data Links, Safety, Target Data Extractor, Digital Measurement Receiver, Sensor Analysis, Flight Termination, Surveillance, Electronic Countermeasures, Terrain Awareness And Warning, Telemetry, Remote Control.
Mission Processing (MP)	Vehicle onboard master data processing unit(s) responsible for coordinating and directing the major mission systems. Ex.: Mission Computer Processing, Avionics, Data Formatting, Air Vehicle Software, Launcher Software, Tactical Data Systems, Data Control And Distribution, Mission Processing, Emergency Systems, Launch and Recovery System, Environmental Control System, Anchoring, Mooring and Towing.
Process Control (PC)	Software that manages the planning, scheduling and execution of a system based on inputs, generally sensor driven.
System Software (SYS)	Layers of software that sit between the computing platform and applications. Ex: Health Management, Link 16, Information Assurance, Framework, Operating System Augmentation, Middleware, Operating Systems.
Planning Software (PLN)	Provides the capability to maximize the use of the platform. The system supports all the mission requirements of the platform and may have the capability to program onboard platform systems with routing, targeting, performance, map, and Intel data.
Scientific Software (SCI)	Non real time software that involves significant computations and scientific analysis. Ex: Environment Simulations, Offline Data Analysis, Vehicle Control Simulators.
Training Software (TRN)	Hardware and software that are used for educational and training purposes. Ex: Onboard or Deliverable Training Equipment & Software, Computer-Based Training.

Table 16 Productivity Types

PT	Description
Telecommunications (TEL)	The transmission of information, e.g. voice, data, commands, images, and video across different mediums and distances. Primarily software systems that control or manage transmitters, receivers and communications channels. Ex: switches, routers, integrated circuits, multiplexing, encryption, broadcasting, protocols, transfer modes, etc.
Software Tools (TOOL)	Software that is used for analysis, design, construction, or testing of computer programs. Ex: Integrated collection of tools for most development phases of the life cycle, e.g. Rational development environment.
Test Software (TST)	Hardware & Software necessary to operate and maintain systems and subsystems which are not consumed during the testing phase and are not allocated to a specific phase of testing. Ex: Onboard or Deliverable Test Equipment & Software.
Intelligence & Information Software (IIS)	An assembly of software applications that allows a properly designated authority to exercise control over the accomplishment of the mission. Humans manage a dynamic situation and respond to user-input in real time to facilitate coordination and cooperation. Ex: Battle Management, Mission Control. Also, software that manipulates, transports and stores information. Ex: Database, Data Distribution, Information Processing, Internet, Entertainment, Enterprise Services*****, Enterprise Information****.**
***** Enterprise Information (subtype of IIS)	HW & SW needed for developing functionality or software service that are unassociated, loosely coupled units of functionality. Examples are: Enterprise service management (monitoring, fault management), Machine-to-machine messaging, Service discovery, People and device discovery, Metadata discovery, Mediation, Service security, Content discovery and delivery, Federated search, Enterprise catalog service, Data source integration, Enterprise content delivery network (caching specification, distributed caching, forward staging), Session management,, Audio & video over internet protocol, Text collaboration (chat, instant messaging), Collaboration (white boarding & annotation), Application broadcasting and sharing, Virtual spaces, Identity management (people and device discovery), User profiling and customization.
****** Enterprise Information (subtype of IIS)	HW & SW needed for assessing and tailoring COTS software applications or modules that can be attributed to a specific software service or bundle of services. Examples of enterprise information systems include but not limited to: , Enterprise resource planning, Enterprise data warehouse, Data mart, Operational data store. Examples of business / functional areas include but not limited to: General ledger, Accounts payable, Revenue and accounts receivable, Funds control and budgetary accounting, Cost management, Financial reporting, Real property inventory and management.

5.2.2.1 Finding the Productivity Type

It can be challenging to determine which productivity type should be used to estimate the cost and schedule of an application (that part of the hardware-software complex which comprise a domain). The productivity types are by design generic. By using a work breakdown structure (WBS), the environment and domain are used to determine the productivity type.

Using the WBS from MIL-STD-881C, a mapping is created from environment to Productivity Type (PT), Table 17. Starting with the environment, traverse the WBS to the lowest level where the domain is represented. Each domain is associated with a Productivity Type (PT). In real-world WBSs, the traverse from environment to PT will most likely not be the same number of levels. However the 881C WBS provides the context for selecting the PT which should be transferable to other WBSs.

Two examples for finding the productivity type using the 881C Aerial Vehicle Manned (AVM) and Space Vehicle Unmanned (SVU) WBS elements are provided below. The highest level WBS element represents the environment. In the AVM environment there are the Avionics subsystem, Fire-Control sub-subsystem, and the sensor, navigation, air data, display, bombing computer and safety domains. Each domain has an associated productivity type.

Table 17 Aerial Vehicle Manned to PT Example

Environment	Subsystem	Sub-subsystem	Domains	PT
AVM	Avionics	Fire Control	Search, target, tracking sensors	SCP
			Self-contained navigation	RTE
			Self-contained air data systems	RTE
			Displays, scopes, or sights	RTE
			Bombing computer	MP
			Safety devices	RTE
		Data Display and Controls	Multi-function display	RTE
			Control display units	RTE
			Display processors	MP
			On-board mission planning	TRN

For a space system, the highest level 881C WBS element is the Space Vehicle Unmanned (SVU). The two sub-systems are Bus and Payload. The domains for Bus address controlling the vehicle. The domains for Payload address controlling the onboard equipment. Each domain has an associated productivity type, Table 18.

Table 18 Space Vehicle Unmanned to PT Example

Environment	Subsystem	Domains	PT
SVU	Bus	Structures & Mechanisms (SMS)	VC
		Thermal Control (TCS)	VC
		Electrical Power (EPS)	VC
		Attitude Control (ACS)	VC
		Propulsion	VC
		Telemetry, Tracking, & Command (TT&C)	RTE
		Bus Flight Software	VC
	Payload	Thermal Control	RTE
		Electrical Power	RTE
		Pointing, Command, & Control Interface	VP
		Payload Antenna	SCP
		Payload Signal Electronics	SCP
		Optical Assembly	SCP
		Sensor	SCP
		Payload Flight Software	VP

The full table is available for the MIL-STD-881C WBS Mapping to Productivity Types, Appendix 9.5.

6 Cost Estimating Relationship Analysis

This chapter discusses using the assessed and process SRDR data to create Cost Estimating Relationships (CER). These relationships are different for different types of software. Factors such as application complexity, impact of loss due to reliability, autonomous modes of operation, constraints on timing, storage and power, security requirements, and complex interfaces influence the cost and time to develop applications. Parametric cost models have a number of adjustable parameters that attempt to account for these factors.

6.1 Application Domain Decomposition

Instead of developing CERs and SERs with many parameters, this chapter describes an analysis approach based on grouping similar software applications together. These groups are called Application Domains. Application Domains implement a combination of hardware and software components to achieve the intended functionality. Instead of using a domain name such as Communications, a better approach is to use a generic software Productivity Type (PT). Also consideration needs to be given to the operating environment that the domain operates within. Both the operating environment and PT are considered in this analysis to produce CERs.

Domain analysis of the SRDR database is presented in the next sections, and provides guidance in developing estimates in the respective domains. Cost and schedule estimating relationships are expressed in different forms. In this manual, they are expressed as a ratio commonly called Productivity and as a simple math equation called a Model.

6.2 SRDR Metric Definitions

The SRDR was discussed in Chapter 4. In Chapter 5 the metrics were discussed for measuring size, effort and schedule.

6.2.1 Software Size

The SRDR data contained a mixture of different code count types. The data in Chapter 5.1.5.1 was used to convert all counts to the logical count type.

For pre-existing code (Auto-Generated, Modified and Reused), if the adaptation parameters were not provided with the data, the guidelines in Chapter 5.1.5.2 were used.

6.2.2 Software Development Activities and Durations

Software CERs have a breadth and a depth. The *breadth* is the number of lifecycle activities covered and the *depth* is the type of labor counted in or across each activity. The activity data in the SRDR is reported following the [ISO 12207] processes for software development. Table 19 shows the 12207 processes and the ones covered by SRDR data. This is the breadth of the CERs reported in this manual.

Table 19 ISO/IEC 12207 Development Activities

	System requirements analysis
	System architectural design
Activities in SRDR data	**Software requirements analysis**
	Software architectural design
	Software detailed design
	Software coding and testing
	Software integration
	Software qualification testing
	System integration
	System qualification testing
	Software installation
	Software acceptance support

Table 20 shows the different labor categories in the SRDR data. Not all of the records had all of the categories. However, the Software Engineering and Assessment categories were reported for in each record. **Table 14** in Chapter 5.1.5.3 provides a distribution of effort across these activities.

Table 20 SRDR Labor Categories

Category	SRDR Labor Categories
Management	Engineering Management Business Management
Software Engineering	Software Requirements Analysis Architecture and Detailed Design Coding and Unit Testing Test and Integration
Assessment	Qualification Testing Development Test Evaluation Support
Support	Software Configuration Management Software Quality Assurance Configuration Audit Development Environment Support Tools Support Documentation Data Preparation Process Management Metrics Training IT Support / Data Center

When comparing results of the CER analysis with other available CER data, it is important to keep in mind the breadth and depth of activities covered. They should be as similar as possible.

6.3 Cost Estimating Relationships (CER)

6.3.1 Model Selection

A common issue in modeling software engineering cost data using the model form below, EQ(15) is whether there are economies or diseconomies of scale in the data, i.e., as the software size increases less effort is required (economy of scale) or as size increases more effort is required (diseconomies of scale). The scaling influence is found in the exponent, B. An estimated value for B < 1.0 indicates an economy of scale. An estimated value of B > 1.0 indicates a diseconomy of scale.

Eq 16 $$Effort = A \times (KESLOC^{B})$$

[Banker-Kemerer 1989] provide a survey of reasons for economies and diseconomies of scale. Their paper attributes economies of scale to:

- Software development tools that increase productivity
- Specialized personnel that are highly productive
- Fixed overhead that does not increase directly with project size thereby producing economies of scale in larger projects

Diseconomies of scale are attributed to:

- Increasing communication paths between project team members
- Larger systems having more complex interface problems
- Increasing the number of people increases the chance of personality conflicts
- Overhead activities increase at a faster than linear rate as project size increases

The results of their research argue for both economies and diseconomies of scale. The economies of scale were observed on small projects and diseconomies of scale were observed on large projects. They present a model, Most Productive Scale Size (MPSS), which finds the break point between small and large projects. The MPSS model is organization dependent.

Our analysis found that diseconomy of scale was difficult to detect on smaller projects (less than 50 KESLOC) and was not always absent (this may have been due to differences in where the cost was allocated by the different data submitters). This, we believe, was due to the presence of fixed start-up costs and management overhead activities, e.g. required reporting by the Government. The conclusion is that the amount of fixed start-up costs and overhead activities on smaller projects has a masking effect on direct labor; skewing the B-exponent to a value < 1.0 (the larger projects had B-exponent values > 1.0).

Our approach was to test the initial equation, Eq 16. If the initial equation shows a B-exponent < 1.0, we examine whether fixed start-up costs and overhead activities were influencing results using a Non Linear Model (NLM):

Eq 17 $$\text{Effort (PM)} = C + (A \times KESLOC^{B})$$

Or

Eq 18 $$\text{Effort (PM)} = C + (KESLOC^{B})$$

Where

- *Effort* is Person Months
- *C* is the *fixed start-up and overhead activity* costs in Person-Months
- *B* is a scaling factor expressing the degree of the diseconomy of scale

If the NLM shows a B-exponent > 1.0, then the NLM is chosen. This model unmasks the influence of fixed start-up costs in a separate variable from the diseconomies of scale present in the data.

A statistic that is not available for NLMs is R^2, the Coefficient of Determination, used to describe how well a regression fits a set of data. This is due to not being able to use regression analysis to derive the NLM. Iterative search techniques are used instead**. When a NLM is displayed, the R^2 is displayed with the marker ***.**

6.3.2 Model-Based CERs Coverage

The coverage of model-based CERs by operating environment and productivity type, discussed in Chapters 5.2.1 and 5.2.2 respectively, are shown in Table 21. The operating environments are the table columns. The productivity types are the rows. Not all productivity types and environments were covered due to lack of enough data in each group (at least 5 records are required).

The shaded cells in Table 21 denote a CER and the number in a cell is the number of records used to create the CER. The “ALL” column and row mean for all operating environments or productivity types.

Table 21 CER Coverage

	Ground Site	Ground Vehicle	Maritime Vessel	Aerial Vehicle	Space Vehicle	Ordinance	ALL
SCP		13		8			36
VC							
VP					16		16
RTE		22		9			52
MP	6			31			48
PC							
SYS	28						60
PLN							
SCI	24						39
TRN							
TEL							
TOOL							
TST							
IIS	23						37
ALL							

6.3.3 Software CERs by OpEnv

6.3.3.1 Ground Site (GS) Operating Environment

Mission Processing

Eq 19 $$PM_{GSF\text{-}MP} = 3.20 + (KESLOC^{1.19})$$

- Number of observations: 6
- Adjusted R2: ***[3]
- Maximum Absolute Deviation: 0.24
- PRED (30): 0.83
- Minimum KESLOC Value: 15
- Maximum KESLOC Value: 91

[3] R^2 is not available for NLMs.

System Software

Eq 20 $$PM_{GSF\text{-}SYS} = 20.86 + (2.35 \times KESLOC^{1.12})$$

Number of observations:	28
Adjusted R2:	***
Maximum Absolute Deviation:	0.19
PRED (30):	0.82
Minimum KESLOC Value:	5
Maximum KESLOC Value:	215

Scientific Systems

Eq 21 $$PM_{GSF\text{-}SCI} = 34.26 + (KESLOC^{1.29})$$

Number of observations:	24
Adjusted R2:	****
Maximum Absolute Deviation:	0.37
PRED (30):	0.56
Minimum KESLOC Value:	5
Maximum KESLOC Value:	171

Intelligence and Information Systems

Eq 22 $$PM_{GSF\text{-}IIS} = 30.83 + (1.38 \times KESLOC^{1.13})$$

Number of observations:	23
Adjusted R2:	***
Maximum Absolute Deviation:	0.16
PRED (30):	0.91
Minimum KESLOC Value:	15
Maximum KESLOC Value:	180

6.3.3.2 Ground Vehicle (GV) Operating Environment

Sensor Control and Processing

Eq 23 $$PM_{GV\text{-}SCP} = 135.5 + (KESLOC^{1.60})$$

Number of observations:	13
Adjusted R2:	***
Maximum Absolute Deviation:	0.39
PRED (30):	0.31
Minimum KESLOC Value:	1
Maximum KESLOC Value:	76

Real Time Embedded

Eq 24 $PM_{GV\text{-}RTE} = 84.42 + (KESLOC^{1.45})$

- Number of observations: 22
- Adjusted R2: ***
- Maximum Absolute Deviation: 0.24
- PRED (30): 0.73
- Minimum KESLOC Value: 9
- Maximum KESLOC Value: 89

6.3.3.3 Aerial Vehicle (AV) Operating Environment

Sensor Control and Signal Processing (SCP)

Eq 25 $PM_{AVM\text{-}SCP} = 115.8 + (KESLOC^{1.61})$

- Number of observations: 8
- Adjusted R2: ***
- Maximum Absolute Deviation: 0.27
- PRED (30): 0.62
- Minimum KESLOC Value: 6
- Maximum KESLOC Value: 162

Real Time Embedded (RTE)

Eq 26 $PM_{AVM\text{-}RTE} = 5.61 \times (KESLOC^{1.16})$

- Number of observations: 9
- Adjusted R2: 0.89
- Maximum Absolute Deviation: 0.50
- PRED (30): 0.33
- Minimum KESLOC Value: 1
- Maximum KESLOC Value: 167

Mission Processing (MP)

Eq 27 $PM_{AVM\text{-}MP} = 3.1 \times (KESLOC^{1.43})$

- Number of observations: 31
- Adjusted R2: 0.88
- Maximum Absolute Deviation: 0.50
- PRED (30): 0.59
- Minimum KESLOC Value: 1
- Maximum KESLOC Value: 207

6.3.3.4 Space Vehicle Unmanned (SVU) Operating Environment

Vehicle Payload

Eq 28 $$PM_{SV\text{-}VP} = 3.15 \times (KESLOC^{1.38})$$

Number of observations:	16
Adjusted R2:	0.86
Maximum Absolute Deviation:	0.27
PRED (30):	0.50
Minimum KESLOC Value:	5
Maximum KESLOC Value:	120

6.3.4 Software CERs by PT Across All Environments

The following environments were included in this analysis:

- Ground Sites
- Ground Vehicles
- Maritime Vessels
- Aerial Vehicle
- Ordnance
- Space Vehicle

Sensor Control and Signal Processing

Eq 29 $$PM_{All\text{-}SCP} = 74.37 + (KESLOC^{1.71})$$

Number of observations:	36
Adjusted R2:	***
Maximum Absolute Deviation:	0.69
PRED (30):	0.31
Minimum KESLOC Value:	1
Maximum KESLOC Value:	162

Vehicle Payload

Eq 30 $$PM_{All\text{-}VP} = 3.15 + (KESLOC^{1.38})$$

Number of observations:	16
Adjusted R2:	***
Maximum Absolute Deviation:	0.27
PRED (30):	0.50
Minimum KESLOC Value:	5
Maximum KESLOC Value:	120

Real Time Embedded

Eq 31 $$PM_{All\text{-}RTE} = 34.32 + (KESLOC^{1.52})$$

Number of observations:	52
Adjusted R2:	***
Maximum Absolute Deviation:	0.61
PRED (30):	0.46
Minimum KESLOC Value:	1
Maximum KESLOC Value:	167

Mission Processing

Eq 32 $$PM_{All\text{-}MP} = 3.48 \times (KESLOC^{1.17})$$

Number of observations:	48
Adjusted R2:	0.88
Maximum Absolute Deviation:	0.49
PRED (30):	0.58
Minimum KESLOC Value:	1
Maximum KESLOC Value:	207

System Software

Eq 33 $$PM_{All\text{-}SYS} = 16.01 + (KESLOC^{1.37})$$

Number of observations:	60
Adjusted R2:	***
Maximum Absolute Deviation:	0.37
PRED (30):	0.53
Minimum KESLOC Value:	2
Maximum KESLOC Value:	215

Scientific Software

Eq 34 $$PM_{All\text{-}SCI} = 21.09 + (KESLOC^{1.36})$$

Number of observations:	39
Adjusted R2:	***
Maximum Absolute Deviation:	0.65
PRED (30):	0.18
Minimum KESLOC Value:	1
Maximum KESLOC Value:	171

Intelligence and Information Systems

Eq 35 $$PM_{All\text{-}IIS} = 1.27 \times (KESLOC^{1.18})$$

Number of observations:	37
Adjusted R2:	0.90
Maximum Absolute Deviation:	0.35
PRED (30):	0.65
Minimum KESLOC Value:	1
Maximum KESLOC Value:	180

Future version of this manual will show CER scatter plots, 95% confidence intervals, as well as expand the number of CERs for productivity types and operating environments.

6.4 Productivity Benchmarks

6.4.1 Model Selection and Coverage

Software productivity refers to the ability of an organization to generate outputs using the resources that it currently has as inputs. Inputs typically include facilities, people, experience, processes, equipment, and tools. Outputs generated include software applications and documentation used to describe them.

Eq 36 *Productivity = Outputs / Inputs = KESLOC / PM*

The metric used to express software productivity is Thousands of Equivalent Source Lines of Code (KESLOC) per Person-Month (PM) of effort. While many other measures exist, KESLOC / PM will be used because most of the data collected by the DoD on past projects is captured using these two measures. While controversy exists over whether or not KESLOC / PM is a good measure, consistent use of this metric (see Metric Definitions) provides for meaningful comparisons of productivity.

Table 22 Productivity Benchmark Coverage

	GSF	MVM	AVM	SVU	OVU	ALL
SCP	13	7	6			38
VC						
VP						
RTE	23	6	9			53
MP	6	7	31			47
PC						
SYS	28	23				60
PLN						
SCI	23	15				39
TRN						
TEL						
TOOL						
TST						
IIS	23					35
ALL	116	67	50	6	16	

The numbers in Table 22 are the number of records analyzed. The ALL column and row are not necessarily the sum of the corresponding columns or rows. A minimum of five or more projects were required to derive a productivity benchmark.

6.4.2 Data Transformation

An Anderson-Darling test of the productivity data revealed a non- normal distribution. A histogram with a gamma distribution overlay visually shows this phenomenon, left plot in Figure 3. A Box-Cox transformation of the productivity data showed that if the data were transformed to log values, the distribution was much closer to a normal distribution, right plot in Figure 3.

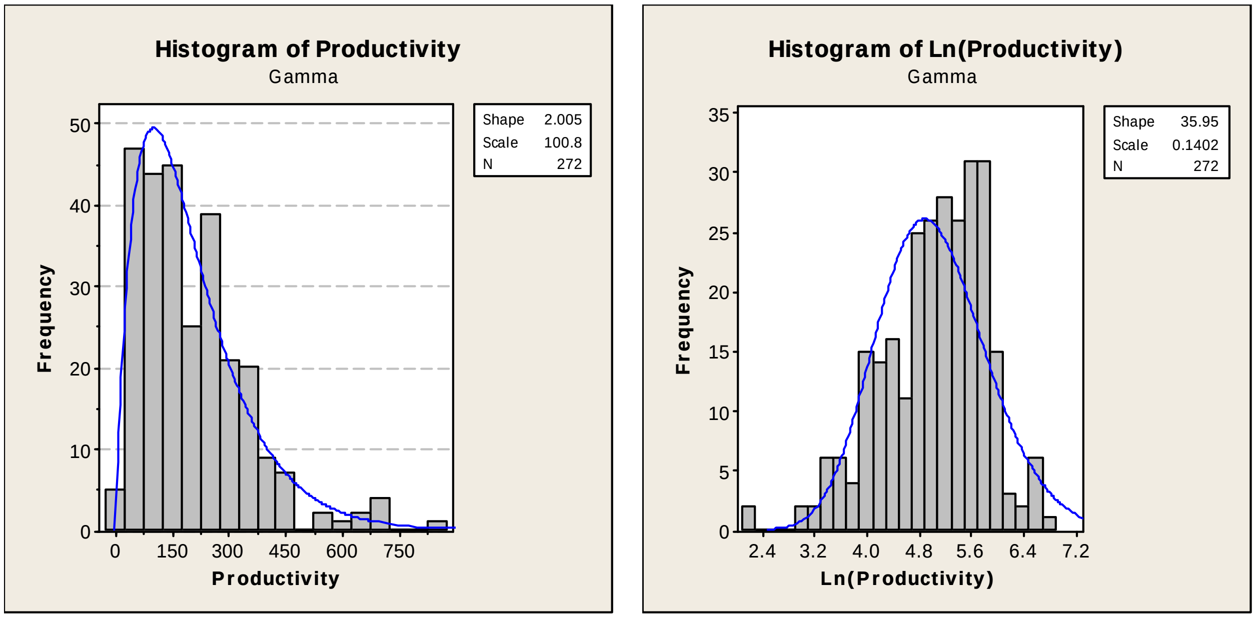


Figure 3 Productivity Data Distribution

This observation required the testing of each data group's distribution for normality. Some groups required different types of transformation and some did not require any transformation at all. The results of the distribution testing are provided in Appendix 9.6.1, Normality Tests on Productivity Data.

Table 24, Table 25, and Table 26 below show the productivity benchmark results. Results shown in *italics* indicate the analysis was performed on transformed data. This is important to note because statistics of data dispersion are only valid on normal distributions, i.e., they only apply in the transformed number space. However, dispersion statistics in the transformed number space do not provide much insight when converted back into linear number space, e.g., dispersion statistics in log number space are much closer together and conversion back into linear number space results in a false measure of dispersion. Therefore the results in these tables are reported in linear number space.

The mean value of the transformed data is valid in linear number space and can be compared to other mean values. The dispersion statistics for the transformed statistics are, strictly speaking, only an indicator of dispersion. The standard deviation, on which the dispersion statistics rely, was derived manually in linear number space.

The transformations performed on each dataset and the statistical summaries are provided in Appendices 9.6.1 and 9.6.2.

6.4.3 Productivity Benchmark Statistics

The tables of productivity results have a number of columns that are defined in Table 23.

Table 23 Productivity Statistics

Column Label	Description
N	Number of records
Min KESLOC	Minimum value in thousands of equivalent source lines of code
Max KESLOC	Maximum value in thousands of equivalent source lines of code
LCI	Lower Confidence Interval is an estimate of an interval below the sample mean within which the population mean is estimated to lie
Mean	Estimated sample value representing the population central value; equal to the sum of the values divided by the number of values , i.e., arithmetic mean
UCI	Upper Confidence Interval is an estimate of an interval above the sample mean within which the population mean is estimated to lie
Std Dev	Standard Deviation is a measure of dispersion about the mean
CV	Coefficient of Variation shows the extent of variability in relation to the mean of the sample. It is defined as the ratio of the standard deviation to the mean.
Q1	Numerical value for the lower 25% of ranked data (1st Quartile), i.e., the value half way between the lowest value and the median in a set of ranked values
Median	Numerical value separating the higher half of a sample from the lower half, i.e., the middle value in a set of ranked values
Q3	Numerical value for the lower 75% of ranked data (3rd Quartile), i.e. the value half way between the median and the highest value in a set of ranked values

6.4.4 Software Productivity Benchmark Results by Operating Environment

Table 24 shows the mean and median productivity across operating environments (OpEnv), discussed in Chapter 5.2.1. To be included in the table, there had to be five or more records in an environment group. The rows are sorted on the mean productivity from lowest to highest.

Table 24 Productivity Benchmarks by Operating Environment

OpEnv	N	Min KESLOC	Max KESLOC	LCI	Mean	UCI	Std Dev	CV	Q1	Median	Q3
SVU	6	5	134	50	85	120	44	52%	52	76	125
OVU	16	0.3	189	88	133	177	90	68%	51	120	226
AVM	50	0.32	208	*108*	133	*158*	*91*	*68%*	81	129	184
MVM	67	2	54	*159*	203	*247*	*184*	*91%*	112	193	717
GSF	116	0.61	215	*182*	205	*227*	*123*	*60%*	118	229	301

Note: Results shown in *italics* indicate the analysis was performed on transformed data. See discussion in 6.3.2.

Using the median values in Table 24, Figure 4 shows a comparison of the productivities across operating environments.

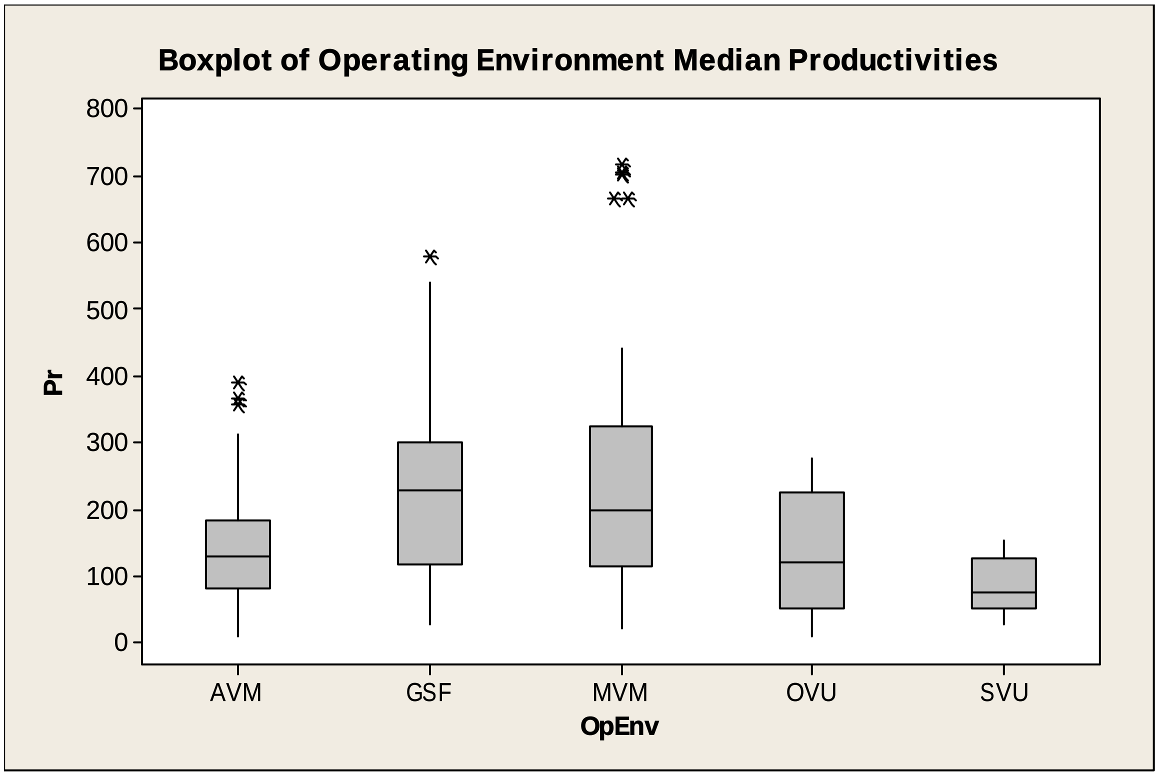


Figure 4 OpEnv Median Productivities Boxplot

6.4.5 Software Productivity Benchmarks Results by Productivity Type

Table 25 shows the mean and median productivity across Productivity Types (PT), discussed in Chapter 5.2.2. To be included in the table, there had to be five or more records in a productivity type group. The rows are sorted on the mean productivity from lowest to highest.

Table 25 Productivity Benchmarks by Productivity Type

PT	N	Min KESLOC	Max KESLOC	LCI	Mean	UCI	Std Dev	CV	Q1	Median	Q3
SCP	38	0.35	162	44	50	56	19	39%	33	53	67
RTE	53	1	167	*100*	120	*140*	*75*	*62%*	83	124	168
MP	47	1	45	*135*	167	*199*	*113*	*68%*	124	159	236
SYS	60	2	215	205	225	245	78	35%	172	219	274
SCI	39	0.32	171	*200*	237	*275*	*120*	*51%*	106	248	313
IIS	35	3	150	*342*	397	*453*	*167*	*42%*	305	363	541

Note: Results shown in *italics* indicate the analysis was performed on transformed data. See discussion in 6.3.2.

Using the median values in Table 25, Figure 5 shows a comparison of the productivities across operating environments.

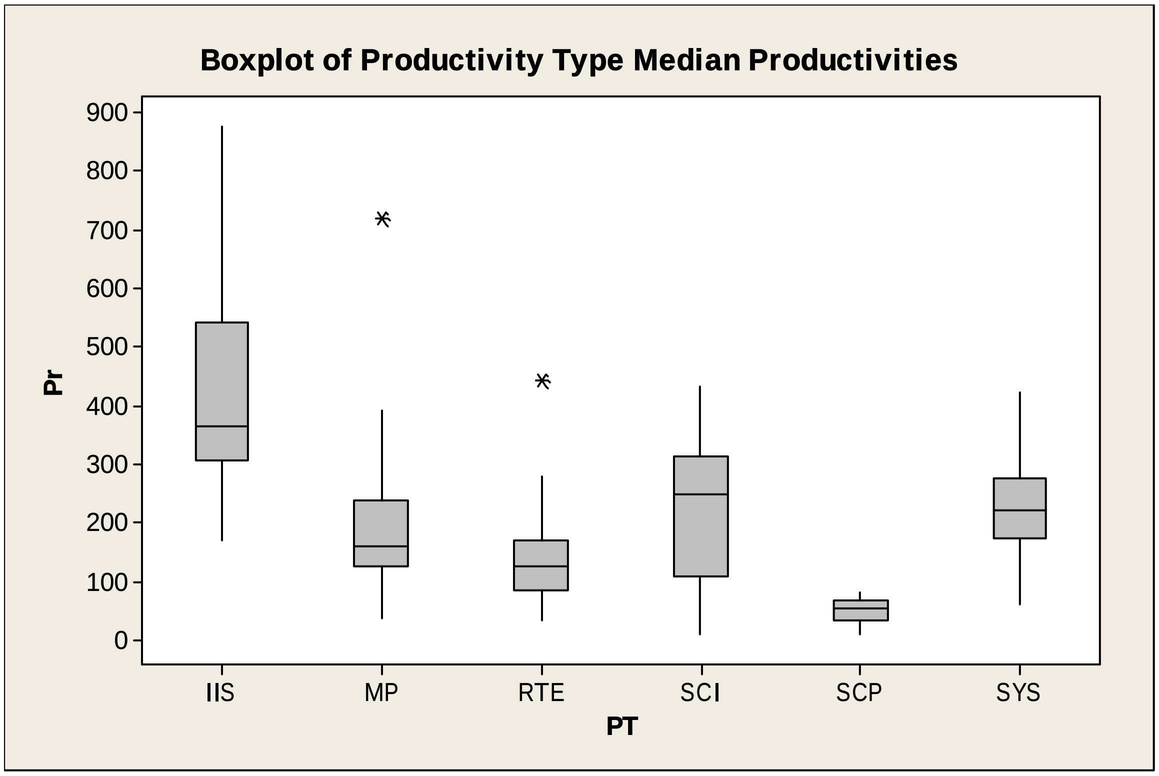


Figure 5 PT Median Productivities Boxplot

6.4.6 Software Productivity Benchmarks by OpEnv and PT

Table 26 shows the mean and median productivity by operating environment (OpEnv) and productivity type (PT). To be included in the table, there had to be five or more records in a productivity type group. The rows are sorted on the mean productivity from lowest to highest in each OpEnv grouping.

Table 26 Productivity Benchmarks by Operating Environment and Productivity Type

OpEnv	PT	N	Min KESLOC	Max KESLOC	LCI	Mean	UCI	Std Dev	CV	Q1	Median	Q3
AVM	SCP	8	6	162	47	56	65	13	23%	46	58	68
AVM	RTE	9	1.5	167	*69*	122	*174*	*80*	*66%*	81	89	237
AVM	MP	31	1.25	207	*123*	154	*186*	*90*	*58%*	122	141	188
GSF	SCP	13	0.61	76	*49*	58	*67*	*17*	*29%*	44	60	67
GSF	RTE	23	9.4	89	110	129	147	45	35%	99	130	149
GSF	MP	6	14.5	91	120	162	203	52	32%	126	158	199
GSF	SYS	28	5.1	215	217	240	264	64	26%	199	245	274
GSF	SCI	23	4.5	171	*230*	271	*312*	*99*	*37%*	201	274	313
GSF	IIS	23	15.2	180	341	376	410	85	23%	305	359	436
MVM	SCP	7	5.99	24	25	39	53	19	50%	24	33	46
MVM	RTE	6	2.21	38	*-13*	113	*239*	*158*	*139%*	62	110	247
MVM	SCI	15	2	54	119	185	251	131	71%	55	170	327
MVM	MP	7	4.931	13	150	189	228	52	28%	136	217	241
MVM	SYS	23	2.05	47	199	234	269	86	37%	184	226	324
OVU	RTE	11	1.2	116	96	141	410	76	54%	56	127	192

Note: Results shown in *italics* indicate the analysis was performed on transformed data. See discussion in 6.3.2.

6.5 Future Work

Productivity is not only influenced by the operating environment and productivity type but also *by application size*. The larger the application being developed, the larger the number of overhead activities required to coordinate the development. In general, productivity decreases as size increases as discussed previously in Section 6.3.1.

For this reason, within an environment and PT, different productivities should be broken out for different size groups:

- 0-25 KESLOC
- 26-50 KESLOC
- 51-100 KESLOC
- 100+ KESLOC

A future version of this manual will use additional data to examine productivity changes within an operating environment and productivity type.

7 Modern Estimation Challenges

Several future trends will present significant future challenges for the sizing and cost estimation of 21st century software systems. Prominent among these trends are:

- Rapid change, emergent requirements, and evolutionary development
- Net-centric systems of systems
- Model-Driven and Non-Developmental Item (NDI)-intensive systems
- Ultrahigh software system assurance
- Legacy maintenance and brownfield development
- Agile and Kanban development

This chapter summarizes each trend and elaborates on its challenges for software sizing and cost estimation.

7.1 Changing Objectives, Constraints and Priorities

7.1.1 Rapid Change, Emergent Requirements, and Evolutionary Development

21st century software systems will encounter increasingly rapid change in their objectives, constraints, and priorities. This change will be necessary due to increasingly rapid changes in their competitive threats, technology, organizations, leadership priorities, and environments. It is thus increasingly infeasible to provide precise size and cost estimates if the systems' requirements are emergent rather than pre-specifiable. This has led to increasing use of strategies such as incremental and evolutionary development, and to experiences with associated new sizing and costing phenomena such as the Incremental Development Productivity Decline. It also implies that measuring the system's size by counting the number of source lines of code (SLOC) in the delivered system may be an underestimate, as a good deal of software may be developed and deleted before delivery due to changing priorities.

There are three primary options for handling these sizing and estimation challenges. The first is to improve the ability to estimate requirements volatility during development via improved data collection and analysis, such as the use of code counters able to count numbers of SLOC added, modified, and deleted during development [Nguyen 2010]. If such data is unavailable, the best one can do is to estimate ranges of requirements volatility. For uniformity, Table 27 presents a recommended set of Requirements Volatility (RVOL) ranges over the development period for rating levels of 1 (Very Low) to 5 (Very High), such as in the DoD SRDR form [DCARC 2005].

Table 27 Recommended RVOL Rating Levels

Rating Level	RVOL Range	RVOL Average
1. Very Low	0-6%	3%
2. Low	6-12%	9%
3. Nominal	12-24%	18%
4. High	24-48%	36%
5. Very High	>48%	72%

For incremental and evolutionary development projects, the second option is to treat the earlier increments as reused software, and to apply reuse factors to them (such as the percent of the design, code, and integration modified, perhaps adjusted for degree of software understandability and programmer unfamiliarity [Boehm et al. 2000]). This can be done either uniformly across the set of previous increments, of by having these factors vary by previous increment or by subsystem. This will produce an equivalent-SLOC (ESLOC) size for the effect of modifying the previous increments, to be added to the size of the new increment in estimating effort for the new increment. In tracking the size of the overall system, it is important to remember that these ESLOC are not actual lines of code to be included in the size of the next release.

The third option is to include an Incremental Development Productivity Decline (IDPD) factor, or perhaps multiple factors varying by increment or subsystem. Unlike hardware, where unit costs tend to decrease with added production volume, the unit costs of later software increments tend to increase, due to previous-increment breakage and usage feedback, and due to increased integration and test effort. Thus, using hardware-driven or traditional software-driven estimation methods for later increments will lead to underestimates and overruns in both cost and schedule.

A relevant example was a large defense software system that had the following characteristics:

- 5 builds, 7 years, $100M
- Build 1 productivity over 300 SLOC / person-month
- Build 5 productivity under 150 SLOC / person-month
    - Including Build 1-4 breakage, integration, rework
    - 318% change in requirements across all builds

A factor-of-2 decrease in productivity across four new builds corresponds to an average build-to-build IDPD factor of 19%. A recent quantitative IDPD analysis of a smaller software system yielded an IDPD of 14%, with significant variations from increment to increment [Tan et al. 2009]. Similar IDPD phenomena have been found for large commercial software such as the multi-year slippages in the delivery of Microsoft's Word for Windows [Gill-Iansiti 1994] and Windows Vista, and for large agile-development projects that assumed a zero IDPD factor [Elssamadisy-Schalliol 2002].

Based on experience with similar projects, the following impact causes and ranges per increment are conservatively stated in Table 28:

Table 28 IDPD Effort Drivers

Less effort due to more experienced personnel, assuming reasonable initial experience level	
• Variation depending on personnel turnover rates	5-20%
More effort due to code base growth	
• Breakage, maintenance of full code base	20-40%
• Diseconomies of scale in development, integration	10-25%
• Requirements volatility, user requests	10-25%

In the best case, there would be 20% more effort (from above -20+20+10+10); for a 4-build system, the IDPD would be 6%.

In the worst case, there would be 85% more effort (from above 40+25+25-5); for a 4-build system, the IDPD would be 23%.

In any case, with fixed staff size, there would be either a schedule increase or incomplete builds. The difference between 6% and 23% may not look too serious, but the cumulative effects on schedule across a number of builds is very serious.

A simplified illustrative model relating productivity decline to number of builds needed to reach 4M ESLOC across 4 builds follows. Assume that the two-year Build 1 production of 1M SLOC can be developed at 200 SLOC / PM. This means it will need 208 developers (500 PM / 24 mo.). Assuming a constant staff size of 208 for all builds. The analysis shown in Figure 6 shows the impact on the amount of software delivered per build and the resulting effect on the overall delivery schedule as a function of the IDPD factor. Many incremental development cost estimates assume an IDPD of zero, and an on-time delivery of 4M SLOC in 4 builds. However, as the IDPD factor increases and the staffing level remains constant, the productivity decline per build stretches the schedule out to twice as long for an IDPD of 20%.

Thus, it is important to understand the IDPD factor and its influence when doing incremental or evolutionary development. Ongoing research indicates that the magnitude of the IDPD factor may vary by type of application (infrastructure software having higher IDPDs since it tends to be tightly coupled and touches everything; applications software having lower IDPDs if it is architected to be loosely coupled), or by recency of the build (older builds may be more stable). Further data collection and analysis would be very helpful in improving the understanding of the IDPD factor.

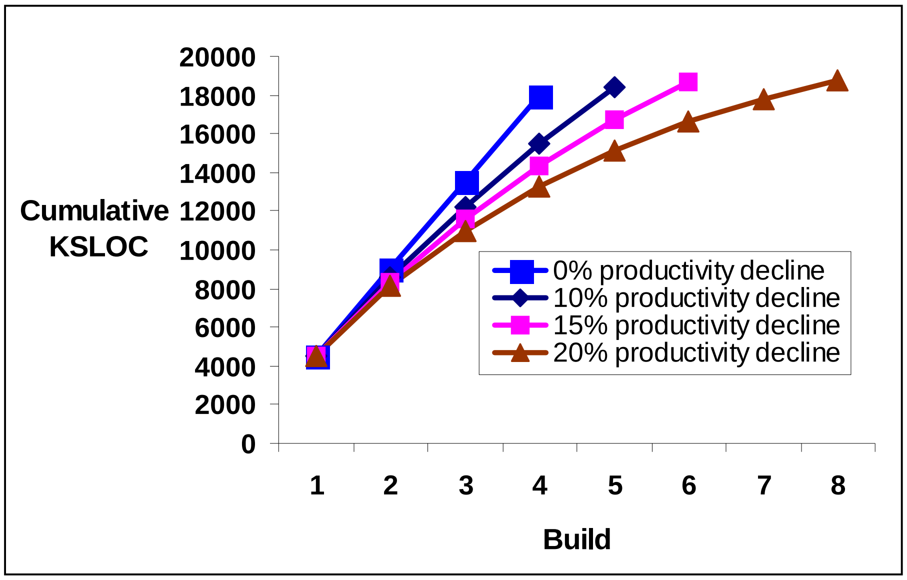


Figure 6 Effects of IDPD on Number of Builds to achieve 4M SLOC

7.1.2 Net-centric Systems of Systems (NCSoS)

If one is developing software components for use in a NCSoS, changes in the interfaces between the component systems and independently-evolving NCSoS-internal or NCSoS-external systems will add further effort. The amount of effort may vary by the tightness of the coupling among the systems; the complexity, dynamism, and compatibility of purpose of the independently-evolving systems; and the degree of control that the NCSoS protagonist has over the various component systems. The latter ranges from Directed SoS (strong control), through Acknowledged (partial control) and Collaborative (shared interests) SoSs , to Virtual SoSs (no guarantees) [USD(AT&L) 2008].

For estimation, one option is to use requirements volatility as a way to assess increased effort. Another is to use existing models such as COSYSMO [Valerdi 2008] to estimate the added coordination effort across the NCSoS [Lane 2009]. A third approach is to have separate models for estimating the systems engineering, NCSoS component systems development, and NCSoS component systems integration to estimate the added effort [Lane-Boehm 2007].

7.1.3 Model-Driven and Non-Developmental Item (NDI)-Intensive Development

Model-driven development and Non-Developmental Item (NDI)-intensive development are two approaches that enable large portions of software-intensive systems to be generated from model directives or provided by NDIs such as Commercial-Off-The-Shelf (COTS) components, open source components, and purchased services such as Cloud services. Figure 7 shows recent trends in the growth of COTS-Based Applications (CBAs) [Yang et al. 2005] and services-intensive systems [Koolmanojwong-Boehm 2010] in the area of web-based e-services.

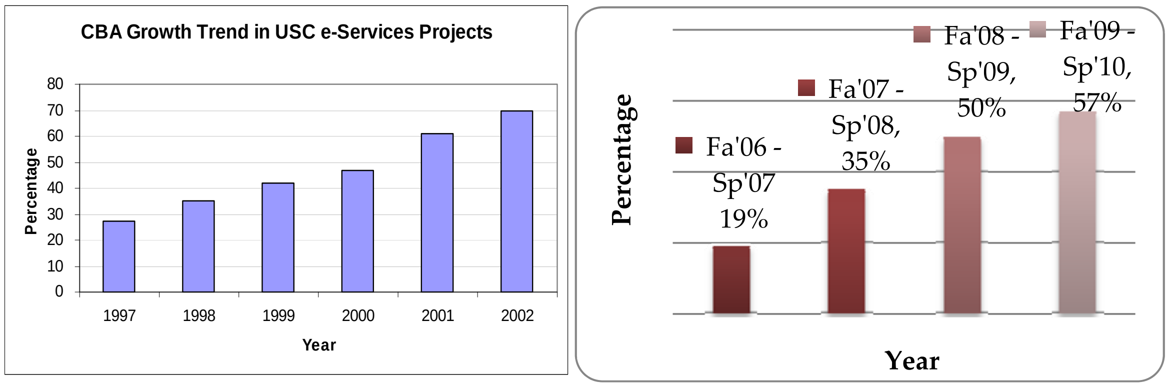


Figure 7 COTS and Services-Intensive Systems Growth in USC E-Services Projects

Such applications are highly cost-effective, but present several sizing and cost estimation challenges:

- Model directives generate source code in Java, C++, or other third-generation languages, but unless the generated SLOC are going to be used for system maintenance, their size as counted by code counters should not be used for development or maintenance cost estimation.

- Counting model directives is possible for some types of model-driven development, but presents significant challenges for others (e.g., GUI builders).
- Except for customer-furnished or open-source software that is expected to be modified, the size of NDI components should not be used for estimating.
- A significant challenge is to find appropriately effective size measures for such NDI components. One approach is to use the number and complexity of their interfaces with each other or with the software being developed. Another is to count the amount of glue-code SLOC being developed to integrate the NDI components, with the proviso that such glue code tends to be about 3 times as expensive per SLOC as regularly-developed code [Basili-Boehm, 2001]. A similar approach is to use the interface elements of function points for sizing [Galorath-Evans 2006].
- A further challenge is that much of the effort in using NDI is expended in assessing candidate NDI components and in tailoring them to the given application. Some initial guidelines for estimating such effort are provided in the COCOTS model [Abts 2004]. • Another challenge is that the effects of COTS and Cloud-services evolution are generally underestimated during software maintenance. COTS products generally provide significant new releases on the average of about every 10 months, and generally become unsupported after three new releases. With Cloud services, one does not have the option to decline new releases, and updates occur more frequently. One way to estimate this source of effort is to consider it as a form of requirements volatility.
- Another serious concern is that functional size measures such as function points, use cases, or requirements will be highly unreliable until it is known how much of the functionality is going to be provided by NDI components or Cloud services.

7.1.4 Ultrahigh Software Systems Assurance

The increasing criticality of software to the safety of transportation vehicles, medical equipment, or financial resources; the security of private or confidential information; and the assurance of "24 / 7" Internet, web, or Cloud services will require further investments in the development and certification of software than are provided by most current software-intensive systems.

While it is widely held that ultrahigh-assurance software will substantially raise software–project cost, different models vary in estimating the added cost. For example, [Bisignani-Reed 1988] estimates that engineering highly–secure software will increase costs by a factor of 8; the 1990's Softcost-R model estimates a factor of 3.43 [Reifer 2002]; the SEER model uses a similar value of 3.47 [Galorath-Evans 2006].

A recent experimental extension of the COCOMO II model called COSECMO used the 7 Evaluated Assurance Levels (EALs) in the ISO Standard Common Criteria for Information Technology Security Evaluation (CC) [ISO 1999], and quoted prices for certifying various EAL security levels to provide an initial estimation model in this context [Colbert-Boehm 2008]. Its added-effort estimates were a function of both EAL level and software size: its multipliers for a 5000-SLOC secure system were 1.50 for EAL 4 and 8.8 for EAL 7.

A further sizing challenge for ultrahigh-assurance software is that it requires more functionality for such functions as security audit, communication, cryptographic support, data protection, etc. These may be furnished by NDI components or may need to be developed for special systems.

7.1.5 Legacy Maintenance and Brownfield Development

Fewer and fewer software-intensive systems have the luxury of starting with a clean sheet of paper or whiteboard on which to create a new Greenfield system. Most software-intensive systems are already in maintenance; [Booch 2009] estimates that there are roughly 200 billion SLOC in service worldwide. Also, most new applications need to consider continuity of service from the legacy system(s) they are replacing. Many such applications involving incremental development have failed because there was no way to separate out the incremental legacy system capabilities that were being replaced. Thus, such applications need to use a Brownfield development approach that concurrently architect the new version and its increments, while re-engineering the legacy software to accommodate the incremental phase-in of the new capabilities [Hopkins-Jenkins 2008; Lewis et al. 2008; Boehm 2009].

Traditional software maintenance sizing models have determined an equivalent SLOC size by multiplying the size of the legacy system by its Annual Change Traffic (ACT) fraction (% of SLOC added + % of SLOC modified) / 100. The resulting equivalent size is used to determine a nominal cost of a year of maintenance, which is then adjusted by maintenance-oriented effort multipliers. These are generally similar or the same as those for development, except for some, such as required reliability and degree of documentation, in which larger development investments will yield relative maintenance savings. Some models such as SEER [Galorath-Evans 2006] include further maintenance parameters such as personnel and environment differences. An excellent summary of software maintenance estimation is in [Stutzke 2005].

However, as legacy systems become larger and larger (a full-up BMW contains roughly 100 million SLOC [Broy 2010]), the ACT approach becomes less stable. The difference between an ACT of 1% and an ACT of 2% when applied to 100 million SLOC is 1 million SLOC. A recent revision of the COCOMO II software maintenance model sizes a new release as ESLOC = 2*(Modified SLOC) + Added SLOC + 0.5* (Deleted SLOC). The coefficients are rounded values determined from the analysis of data from 24 maintenance activities [Nguyen, 2010], in which the modified, added, and deleted SLOC were obtained from a code counting tool. This model can also be used to estimate the equivalent size of re-engineering legacy software in Brownfield software development. At first, the estimates of legacy SLOC modified, added, and deleted will be very rough, and can be refined as the design of the maintenance modifications or Brownfield re-engineering is determined.

7.1.6 Agile and Kanban Development

The difficulties of software maintenance estimation can often be mitigated by using workflow management techniques such as Kanban [Anderson 2010]. In Kanban, individual maintenance upgrades are given Kanban cards (Kanban is the Japanese word for card; the approach originated with the Toyota Production System). Workflow management is accomplished by limiting the number of cards introduced into the development process, and pulling the cards into the next stage of development (design, code, test, release) when open capacity is available (each stage has a limit of the number of cards it can be processing at a given time). Any buildups of upgrade queues waiting to be pulled forward are given management attention to find and fix bottleneck root causes or to rebalance the manpower devoted to each stage of development. A key Kanban principle is to minimize work in progress.

An advantage of Kanban is that if upgrade requests are relatively small and uniform, that there is no need to estimate their required effort; they are pulled through the stages as capacity is available, and if the capacities of the stages are well-tuned to the traffic, work gets done on schedule. However, if a too-large upgrade is introduced into the system, it is likely to introduce delays as it progresses through the stages. Thus, some form of estimation is necessary to determine right-size upgrade units, but it does not have to be precise as long as the workflow management pulls the upgrade through the stages. For familiar systems, performers will be able to right-size the units. For Kanban in less-familiar systems, and for sizing builds in agile methods such as Scrum, group consensus techniques such as Planning Poker [Cohn 2005] or Wideband Delphi [Boehm 1981]can generally serve this purpose.

The key point here is to recognize that estimation of knowledge work can never be perfect, and to create development approaches that compensate for variations in estimation accuracy. Kanban is one such; another is the agile methods' approach of timeboxing or schedule-as-independent-variable (SAIV), in which maintenance upgrades or incremental development features are prioritized, and the increment architected to enable dropping of features to meet a fixed delivery date (With Kanban, prioritization occurs in determining which of a backlog of desired upgrade features gets the next card). Such prioritization is a form of value-based software engineering, in that the higher-priority features can be flowed more rapidly through Kanban stages [Anderson 2010], or in general given more attention in defect detection and removal via value-based inspections or testing [Boehm-Lee 2005; Li-Boehm 2010]. Another important point is that the ability to compensate for rough estimates does not mean that data on project performance does not need to be collected and analyzed. It is even more important as a sound source of continuous improvement and change adaptability efforts.

7.1.7 Putting It All Together at the Large-Project or Enterprise Level

The biggest challenge of all is that the six challenges above need to be addressed concurrently. Suboptimizing on individual-project agility runs the risks of easiest-first lock-in to unscalable or unsecurable systems, or of producing numerous incompatible stovepipe applications. Suboptimizing on security assurance and certification runs the risks of missing early-adopter market windows, of rapidly responding to competitive threats, or of creating inflexible, user-unfriendly systems.

One key strategy for addressing such estimation and performance challenges is to recognize that large systems and enterprises are composed of subsystems that have different need priorities and can be handled by different estimation and performance approaches. Real-time, safety-critical control systems and security kernels need high assurance, but are relatively stable. GUIs need rapid adaptability to change, but with GUI-builder systems, can largely compensate for lower assurance levels via rapid fixes. A key point here is that for most enterprises and large systems, there is no one-size-fits-all method of sizing, estimating, and performing.

7.2 Estimation Approaches for Different Processes

This implies a need for guidance on what kind of process to use for what kind of system or subsystem, and on what kinds of sizing and estimation capabilities fit what kinds of processes. A start toward such guidance is provided in Tables 3.3 and 3.4 in [Boehm-Lane 2010].

Figure 8 summarizes the traditional single-step waterfall process plus several forms of incremental development, each of which meets different competitive challenges and which are best served by different cost estimation approaches. The time phasing of each form is expressed in terms of the increment 1, 2, 3, … content with respect to the Rational Unified Process (RUP) phases of Inception (I), Elaboration (E), Construction (C), and Transition (T):

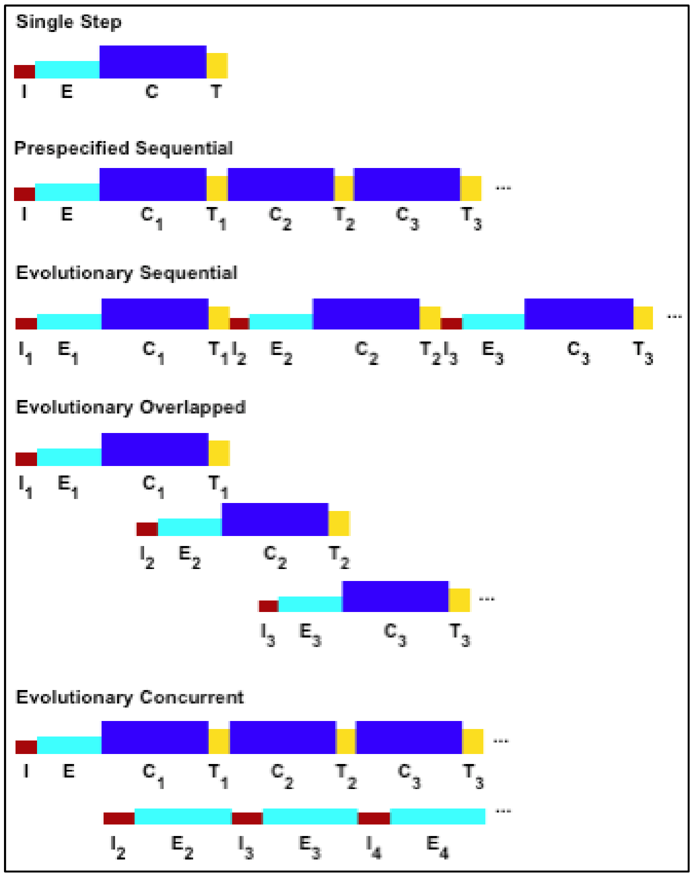


Figure 8 Summary of Different Processes

The Single Step model is the traditional waterfall model, in which the requirements are pre-specified, and the system is developed to the requirements in a single increment. Single-increment parametric estimation models, complemented by expert judgment, are best for this process.

The Pre-specified Sequential incremental development model is not evolutionary. It just splits up the development in order to field an early Initial Operational Capability, followed by several Pre-Planned Product Improvements (P3Is). When requirements are pre-specifiable and stable, it enables a strong, predictable process. When requirements are emergent and / or rapidly changing, it often requires very expensive rework when it needs to undo architectural commitments. Cost estimation can be performed by sequential application of single-step parametric models plus the use of an IDPD factor, or by parametric model extensions supporting the estimation of increments, including options for increment overlap and breakage of existing increments, such as the extension of COCOMO II Incremental Development Model (COINCOMO) extension described in Appendix B of [Boehm et al. 2000].

The Evolutionary Sequential model rapidly develops an initial operational capability and upgrades it based on operational experience. Pure agile software development fits this model: if something is wrong, it will be fixed in 30 days in the next release. Rapid fielding also fits this model for larger or hardware-software systems. Its strength is getting quick-response capabilities in the field. For pure agile, it can fall prey to an easiest-first set of architectural commitments which break when, for example, it tries to add security or scalability as a new feature in a later increment. For rapid fielding, it may be expensive to keep the development team together while waiting for usage feedback, but it may be worth it. For small agile projects, group consensus techniques such as Planning Poker are best; for larger projects, parametric models with an IDPD factor are best.

Evolutionary Overlapped covers the special case of deferring the next increment until critical enablers such as desired new technology, anticipated new commercial product capabilities, or needed funding become available or mature enough to be added.

Evolutionary Concurrent has the systems engineers handling the change traffic and re-baselining the plans and specifications for the next increment, while keeping the development stabilized for the current increment. Its example and pros and cons are provided in Table 29.

Table 29 Situation-Dependent Processes and Estimation Approaches

Type	Examples	Pros	Cons	Cost Estimation
Single Step	Stable; High Assurance	Pre-specifiable full-capability requirements	Emergent requirements or rapid change	Single-increment parametric estimation models
Pre-specified Sequential	Platform base plus PPPIs	Pre-specifiable full-capability requirements	Emergent requirements or rapid change	COINCOMO or repeated single-increment parametric model estimation with IDPD
Evolutionary Sequential	Small: Agile Large: Evolutionary Development	Adaptability to change	Easiest-first; late, costly breakage	Small: Planning-poker-type Large: Parametric with IDPD and Requirements Volatility
Evolutionary Overlapped	COTS-intensive systems	Immaturity risk avoidance	Delay may be noncompetitive	Parametric with IDPD and Requirements Volatility
Evolutionary Concurrent	Mainstream product lines; Systems of systems	High assurance with rapid change	Highly coupled systems with very rapid change	COINCOMO with IDPD for development; COSYSMO for re-baselining

All Cost Estimation approaches also include an expert-judgment cross-check.

Table 30 provides criteria for deciding which of the five classes of incremental and evolutionary acquisition (EvA) defined in Table 29 to use, plus the choice of non-incremental, single-step development.

The Single-Step-to-Full-Capability process exemplified by the traditional waterfall or sequential Vee model is appropriate if the product's requirements are pre-specifiable and have a low probability of significant change; and if there is no value in or opportunity to deliver a partial product capability. A good example would be the hardware portion of a geosynchronous satellite.

The Pre-specified Sequential process is best if the product's requirements are pre-specifiable and have a low probability of significant change; and if waiting for the full system to be developed incurs a loss of important and deliverable incremental mission capabilities. A good example would be a well-understood and well-prioritized sequence of software upgrades to a programmable radio.

The Evolutionary Sequential process is best when there is a need to get operational feedback on a quick-response capability before defining and developing the next increment's content. Agile methods fit into this category, as do systems undergoing rapid competitive change.

The Evolutionary Overlapped process is best when one does not need to wait for operational feedback, but may need to wait for next-increment enablers such as technology maturity, external system capabilities, or needed resources. A good example is the need to wait for a mature release of an anticipated commercial product. The Evolutionary Concurrent process is best when the enablers are available, but there is a great deal of change traffic to be handled that would destabilize the team developing the current increment. Examples may be new competitive threats, emergent user capability needs, external system interface changes, technology matured on other programs, or COTS upgrades.

Table 30 Process Model Decision Table

Type	Stable pre-specifiable requirements?	OK to wait for full system to be developed?	Need to wait for next-increment priorities?	Need to wait for next-increment enablers?
Single Step	Yes	Yes		
Pre-specified Sequential	Yes	No		
Evolutionary Sequential	No	No	Yes	
Evolutionary Overlapped	No	No	No	Yes
Evolutionary Concurrent	No	No	No	No

- Example enablers: Technology maturity; External-system capabilities; Needed resources

8 Conclusions and Next Steps

There are two conclusions that can be drawn from the results presented in Chapter 6 Cost Estimating Relationship Analysis:

1. The results do not provide enough certainty to be useful. In which case the reader may be advised to be cautious of any productivity metrics.
2. The results have validity but more investigation is needed into the variability of the data and analysis of additional data is needed as well.

This manual is still a work in progress. There are more SRDR records to be analyzed. With more data, the results presented would be expanded and refined. The list below presents an overview of the next steps:

- Expand the SLOC count type conversions for each of the six programming languages.
- Expand the adapted code parameter table to additional productivity types and operating environments.
- Expand the average effort percentages table, Table 14, to additional productivity types.
- Analysis of schedule duration for the different activities will be conducted.
- Expand the number of CERs for each productivity types and operating environments.
- Increase the coverage of the productivity benchmarks for each operating environment and productivity type.
- Segment the productivity benchmarks by software size groups.

There are two additional chapters that should be in this manual:

1. Software Code Growth
   This is a very important topic as it will impact the sensitivities of a CER-based estimate.
2. Software Maintenance CERs and Productivity Benchmarks
   With the super-large base of DoD software, maintenance cost estimations are another important topic.

9 Appendices

9.1 Acronyms

4GL	Fourth Generation Language
AAF	Adaptation Adjustment Factor: It is used with adapted software to produce an equivalent size. It includes the effects of Design Modified (DM), Code Modified (CM), and Integration Modified (IM).
AAM	Adaptation Adjustment Multiplier
ACAT	Acquisition Category
ACEIT	Automated Cost Estimating Integrated Tools
ACWP	Actual Cost of Work Performed
AMS	Acquisition Management System
ASP	Acquisition Support Plan
AV	Aerial Vehicle
AVM	Aerial Vehicle Manned, e.g., Fixed-wing aircraft, Helicopters
AVU	Aerial Vehicle Unmanned, e.g., Remotely piloted air vehicles
BCWP	Budgeted Cost of Work Performed
BCWS	Budgeted Cost of Work Scheduled
BFP	Basic Feature Point
C/SCSC	Costs / Schedule Control System Criteria
CAPE	Cost Assessment and Program Evaluation (an OSD organization)
CARD	Cost Analysis Requirements Document
CDA	Central Design Authority
CDD	Capability Description Document
CDR	Critical Design Review
CDRL	Contract Data Requirements List
CER	Cost Estimating Relationship
CER	Cost Estimating Relationship
CM	Code Modified Percentage
CMM	Capability Maturity Model

CO	Contracting Officer
COCOMO	COnstructive COst MOdel
COCOTS	COnstructive COTS
COTS	Commercial-off-the Shelf
CPM	Critical Path Method
CSC	Computer Software Component
CSCI	Computer Software Configuration Item
CSDR	Cost and Software Data Report
CSU	Computer Software Unit
DACIMS	Defense Automated Cost Information Management System
DCARC	Defense Cost and Resource Center
DDE	Dynamic Data Exchange
DM	Design Modified Percentage
DoD	Department of Defense
EA	Evolutionary Acquisition
EI	External Inputs
EIF	External Interfaces
EO	External Outputs
EQ	External Inquiries
EVMS	Earned Value Management System
FAA CEH	FAA Cost Estimating Handbook
FAA PH	FAA Pricing Handbook
FAQ	Frequently Asked Questions
FCA	Functional Configuration Audit
FPA	Function Point Analysis
FPC	Function Point Count
FPH	FAA Pricing Handbook
GAO	U.S. General Accounting Office
GS	Ground Site
GSF	Ground Site Fixed, e.g., Command Post, Ground Operations Center, Ground Terminal, Test Faculties

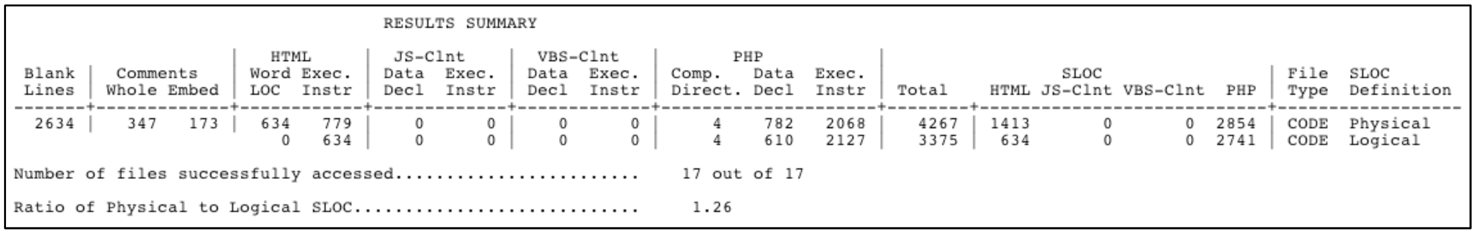
GSM	Ground Site Mobile, e.g., Intelligence gathering stations mounted on vehicles, Mobile missile launcher
GUI	Graphical User Interface
GV	Ground Vehicle
GVM	Ground Vehicle Manned, e.g., Tanks, Howitzers, Personnel carrier
GVU	Ground Vehicle Unmanned, e.g., Robot vehicles
HOL	Higher Order Language
HWCI	Hardware Configuration item
IDPD	Incremental Development Productivity Decline
ICE	Independent Cost Estimate
IEEE	Institute of Electrical and Electronics Engineers
IFPUG	International Function Point User's Group
IIS	Intelligence and Information Software
ILF	Internal Files
IM	Integration Modified Percentage
IRS	Interface Requirement Specification
IS	Information System
KDSI	Thousands of Delivered Source Instructions
LCC	Life Cycle Cost
MDAP	Major Defense Acquisition Program
MOU	Memorandum of Understanding
MPSS	Most Productive Scale Size
MTTD	Mean-Time-To-Detect
MP	Mission Processing
MSLOC	Millions of source lines of code
MV	Maritime Vessel
MVM	Maritime Vessel Manned, e.g., Aircraft carriers, destroyers, supply ships, submarines
MVU	Maritime Vessel Unmanned, e.g., Mine hunting systems, Towed sonar array
NASA	National Aeronautics and Space Administration
NCCA	Naval Center for Cost Analysis

NDI	Non-Development Item
NLM	Non-Linear Model
NRaD	United States Navy's Naval Command, Control, Surveillance Center, RDT&E Division, Software Engineering Process Office
OO	Object Oriented
OpEnv	Operating Environment
OSD	Office of the Secretary of Defense
OV	Ordinance Vehicle
OVU	Ordinance Vehicle Unmanned, e.g., Air-to-air missiles, Air-to-ground missiles, Smart bombs, Strategic missiles
PCA	Physical Configuration Audit
PERT	Program Evaluation and Review Technique
PC	Process Control
PLN	Planning software
Pr	Productivity
PT	Productivity Type
RTE	Real-Time Embedded
RUP	Rational Unified Process
SAIV	Schedule As an Independent Variable
SCI	Scientific software
SCP	Sensor Control and Signal Processing (SCP)
SDD	Software Design Document
SDP	Software Development Plan
SDR	Software Design Review
SEER	A tool suite produced by Galorath
SEER-SEM	System Evaluation and Estimation of Resources Software Estimating Model
SEI	Software Engineering Institute
SER	Schedule Estimating Relationship
SLIM	A tool suite produced by Quantitative Software Management
SLIM	Software Life Cycle Model
SLOC	Source Lines of Code

SRDR	Software Resource Data Report
SRR	Systems Requirements Review
SRS	Software Requirements Specification
SSCAG	Space Systems Cost Analysis Group
SSR	Software Specification Review
SSS	System Segment Specification
SU	Software Understanding
SV	Space Vehicle
SVM	Space Vehicle Manned, e.g., Passenger vehicle, Cargo vehicle, Space station
SVU	Space Vehicle Unmanned, e.g., Orbiting satellites (weather, communications), Exploratory space vehicles
SYS	System Software
TEL	Telecommunications software
TOOL	Software Tools
TST	Test software
TRN	Training Software
UCC	Universal Code Counter
UNFM	Programmer Unfamiliarity
USC	University of Southern California
VC	Vehicle Control
VP	Vehicle Payload
WBS	Work Breakdown Structure

9.2 Automated Code Counting

Unified Code Count is a source code counting and differencing tool. It allows the user to count, compare, and collect both physical and logical differentials between two versions of the source code of a software product. The differencing capabilities allow users to count the number of added / new, deleted, modified, and unmodified physical and logical source lines of code (SLOC) of the current version in comparison with the previous version. With the counting capabilities, users can generate the physical, non-commented source statements, logical SLOC counts, and other sizing information, such as comment and keyword counts, of the target program. The tool can be compiled using a C/C++ supported compiler. It is run by providing files of filenames to be counted or providing the directories where the files reside. It can be downloaded free from the USC Center for Systems and Software Engineering[4].



```
                                      RESULTS SUMMARY

 Blank |       Comments       |    HTML     |  JS-Clnt    |  VBS-Clnt   |          PHP          |
 Lines | Whole Embed | Word Exec. | Data  Exec. | Data  Exec. | Comp.   Data  Exec. | Total    HTML JS-Clnt VBS-Clnt  PHP | File  SLOC
       |             | LOC   Instr | Decl  Instr | Decl  Instr | Direct. Decl  Instr |                SLOC                 | Type  Definition
-------+-------------+-------------+-------------+-------------+---------------------+--------+------------------------------+-----------------
  2634 |   347   173 |  634    779 |    0      0 |    0      0 |     4    782   2068 |   4267 | 1413       0          0  2854 | CODE  Physical
                           0    634 |    0      0 |    0      0 |     4    610   2127 |   3375 |  634       0          0  2741 | CODE  Logical

Number of files successfully accessed........................    17 out of 17

Ratio of Physical to Logical SLOC............................     1.26
```

Figure 9 Unified Code Count Summary Output Example

The example in Figure 9 shows the summary SLOC count with a total of 3,375 Logical SLOC consisting of 619 data declarations and 2,127 executable instructions. This is the software size to be used for estimation, measurement of actuals, and model calibration

9.3 Additional Adapted SLOC Adjustment Factors

Software Understanding

Software Understanding (SU) measures how understandable is the software to be modified. The SU increment is expressed quantitatively as a percentage. SU is determined by taking an average of its ratings on structure, applications clarity, and self-descriptiveness using Table 31 below.

[4] http://csse.usc.edu/research/CODECOUNT/

Table 31 Rating Scale for Software Understanding

	Very Low	Low	Nominal	High	Very High
Structure	Very low cohesion, high coupling, spaghetti code.	Moderately low cohesion, high coupling.	Reasonably well-structured; some weak areas.	High cohesion, low coupling.	Strong modularity, information hiding in data / control structures.
Application Clarity	No match between program and application world-views.	Some correlation between program and application.	Moderate correlation between program and application.	Good correlation between program and application.	Clear match between program and application world-views.
Self-Descriptive-ness	Obscure code; documentation missing, obscure or obsolete.	Some code commentary and headers; some useful documentation.	Moderate level of code commentary, headers, documentation.	Good code commentary and headers; useful documentation; some weak areas.	Self-descriptive code; documentation up-to-date, well-organized, with design rationale.
SU Increment to ESLOC	50	40	30	20	10

Programmer Unfamiliarity

Unfamiliarity (UNFM) quantifies how unfamiliar with the software to be modified is the person modifying it. The UNFM factor described is applied multiplicatively to SU to account for the familiarity. For example, a person who developed the adapted software and is intimate with it does not have to undertake the understanding effort. See Table 32 below.

Table 32 Rating Scale for Programmer Unfamiliarity

UNFM Increment to ESLOC	Level of Unfamiliarity
0.0	Completely familiar
0.2	Mostly familiar
0.4	Somewhat familiar
0.6	Considerably familiar
0.8	Mostly unfamiliar
1.0	Completely unfamiliar

The nonlinear effects for SU and UNFM are added to the linear approximation given by AAF (discussed in Chapter 2.3.2)to compute ESLOC. A higher fidelity adapted code adjustment factor is given by the Adaptation Adjustment Multiplier (AAM):

Eq 37 $AAM = AAF \times (1 + 0.02 \times SU \times UNFM) \text{ (when } AAF \leq 50\%)$

Eq 38 $AAM = AAF + (SU \times UNFM) \text{ (when } AAF > 50\%)$

The new total equivalent size for software composed of new and adapted software is:

Eq 39 $\text{Total Equivalent Size} = \text{New Size} + (AAM \times \text{Adapted Size})$

9.3.1 Examples

9.3.1.1 Example: New Software

A system is to be developed all new. There is no legacy software or other reusable software used. The only size input for estimation is New and there are no adaptation parameters involved.

9.3.1.2 Example: Modified Software

This example estimates the equivalent size associated with writing a new user interface to work with an existing application. Assume the size of the new interface is 20 KSLOC. For it to work, we must change the existing application to accommodate a new Application Program Interface (API). If the adapted size estimate is 100 KSLOC as follows under the assumption that the original code size was 8 KSLOC we compute:

Eq 40 $AAM = [0.4 \times (5\%\ DM) + 0.3 \times (10\%\ CM) + 0.3 \times (10\%\ IM)] \times [100\ KSLOC]$
$= 8\ KSLOC$

Further assume that we are dealing with poorly-written spaghetti code and that we are totally unfamiliar with it. We would then rate SU as 50% and UNFM as 1. As a result, we would have to increase our estimate to reflect this learning curve.

9.3.1.3 Example: Upgrade to Legacy System

In this example there is a very large existing legacy system undergoing periodic upgrades. The size of the legacy system is so large that the equivalent size to estimate the incremental update is very sensitive to the adaptation parameters. The size metrics for the increment are:

- New code: 75 KSLOC
- Modified code: 20 KSLOC
- Legacy code: 3 MSLOC

Care must be taken when assigning the adaptation parameters for the legacy code to compute its equivalent size. For example, the difference between the small values of AAF = 0% and AAF = 5% is a tripling of the equivalent size for the upgrade. Some regression testing of untouched legacy code is inevitable and the factor for % Integration Required should be investigated carefully in terms of the relative effort involved. This might be done by quantifying the number the regression tests performed and their manual intensity compared to the tests of new functionality. If the % Integration Required for the legacy code is 1% then the adaption factor for it would be:

Eq 41 $$AAM = [0.4 \times (0\%\ DM) + 0.3 \times (0\%\ CM) + 0.3 \times (1\%\ IM)] = 0.003$$

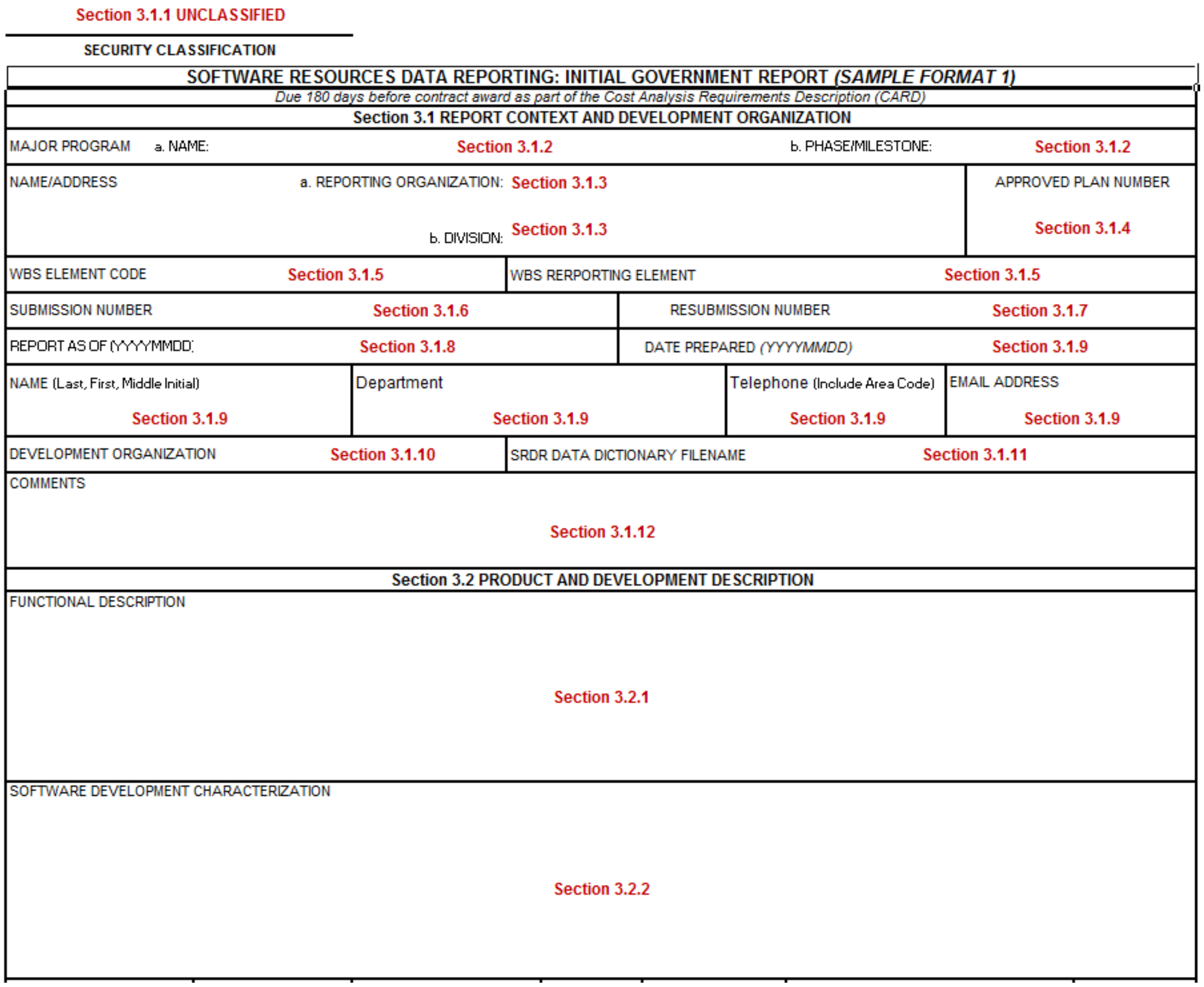
The total ESLOC for new, modified and reused (legacy) assuming the AAF for the modified code is 25% is:

Eq 42 $$ESLOC = 75 + (20 \times 0.25) + (3\ MSLOC \times 0.003) = 75 + 5 + 9 = 89\ KSLOC$$

In this case, building on top of the legacy baseline was 9 / 89 or about 10% of the work.

9.4 SRDR Data Report

The SRDR Data Report has several versions reflecting its evolution over past years: 2003, 2004, 2007 and 2001. The report does not require a specify format for data submission. However, there is a recommend format submitters may use. This format looks like a data form and consists of two pages. See the Figure 10 and Figure 11 below.



Section 3.1.1 UNCLASSIFIED

SECURITY CLASSIFICATION

SOFTWARE RESOURCES DATA REPORTING: INITIAL GOVERNMENT REPORT *(SAMPLE FORMAT 1)*

Due 180 days before contract award as part of the Cost Analysis Requirements Description (CARD)

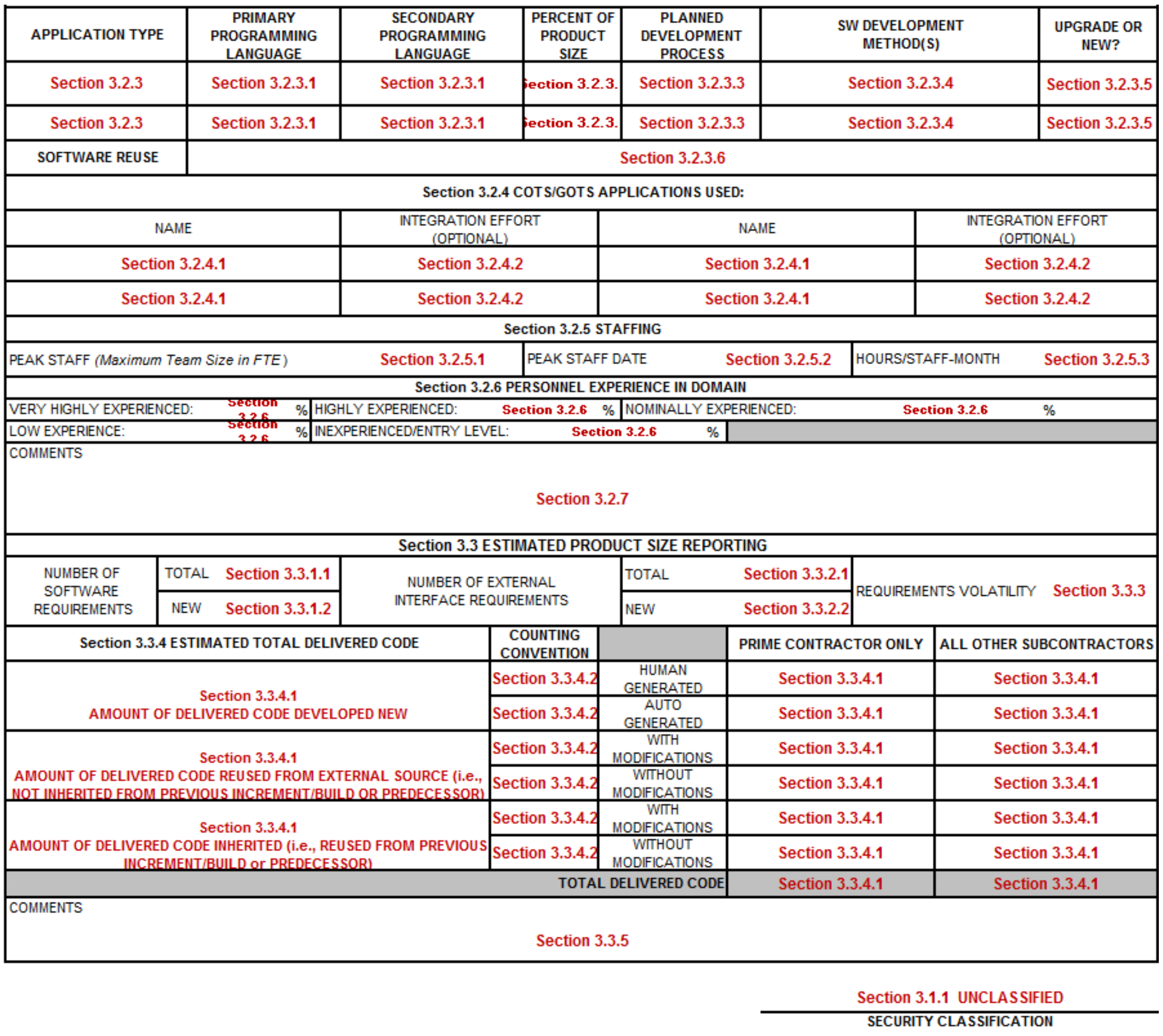
Section 3.1 REPORT CONTEXT AND DEVELOPMENT ORGANIZATION

MAJOR PROGRAM a. NAME: Section 3.1.2		b. PHASE/MILESTONE: Section 3.1.2	
NAME/ADDRESS a. REPORTING ORGANIZATION: Section 3.1.3 b. DIVISION: Section 3.1.3			APPROVED PLAN NUMBER Section 3.1.4
WBS ELEMENT CODE Section 3.1.5		WBS RERPORTING ELEMENT Section 3.1.5	
SUBMISSION NUMBER Section 3.1.6		RESUBMISSION NUMBER Section 3.1.7	
REPORT AS OF (YYYYMMDD) Section 3.1.8		DATE PREPARED *(YYYYMMDD)* Section 3.1.9	
NAME (Last, First, Middle Initial) Section 3.1.9	Department Section 3.1.9	Telephone (Include Area Code) Section 3.1.9	EMAIL ADDRESS Section 3.1.9
DEVELOPMENT ORGANIZATION Section 3.1.10		SRDR DATA DICTIONARY FILENAME Section 3.1.11	
COMMENTS Section 3.1.12			

Section 3.2 PRODUCT AND DEVELOPMENT DESCRIPTION

FUNCTIONAL DESCRIPTION Section 3.2.1
SOFTWARE DEVELOPMENT CHARACTERIZATION Section 3.2.2

Figure 10 SRDR Page 1 (top)



APPLICATION TYPE	PRIMARY PROGRAMMING LANGUAGE	SECONDARY PROGRAMMING LANGUAGE	PERCENT OF PRODUCT SIZE	PLANNED DEVELOPMENT PROCESS	SW DEVELOPMENT METHOD(S)	UPGRADE OR NEW?
Section 3.2.3	Section 3.2.3.1	Section 3.2.3.1	ection 3.2.3.	Section 3.2.3.3	Section 3.2.3.4	Section 3.2.3.5
Section 3.2.3	Section 3.2.3.1	Section 3.2.3.1	ection 3.2.3.	Section 3.2.3.3	Section 3.2.3.4	Section 3.2.3.5
SOFTWARE REUSE	Section 3.2.3.6					

Section 3.2.4 COTS/GOTS APPLICATIONS USED:			
NAME	INTEGRATION EFFORT (OPTIONAL)	NAME	INTEGRATION EFFORT (OPTIONAL)
Section 3.2.4.1	Section 3.2.4.2	Section 3.2.4.1	Section 3.2.4.2
Section 3.2.4.1	Section 3.2.4.2	Section 3.2.4.1	Section 3.2.4.2

Section 3.2.5 STAFFING					
PEAK STAFF *(Maximum Team Size in FTE)*	Section 3.2.5.1	PEAK STAFF DATE	Section 3.2.5.2	HOURS/STAFF-MONTH	Section 3.2.5.3

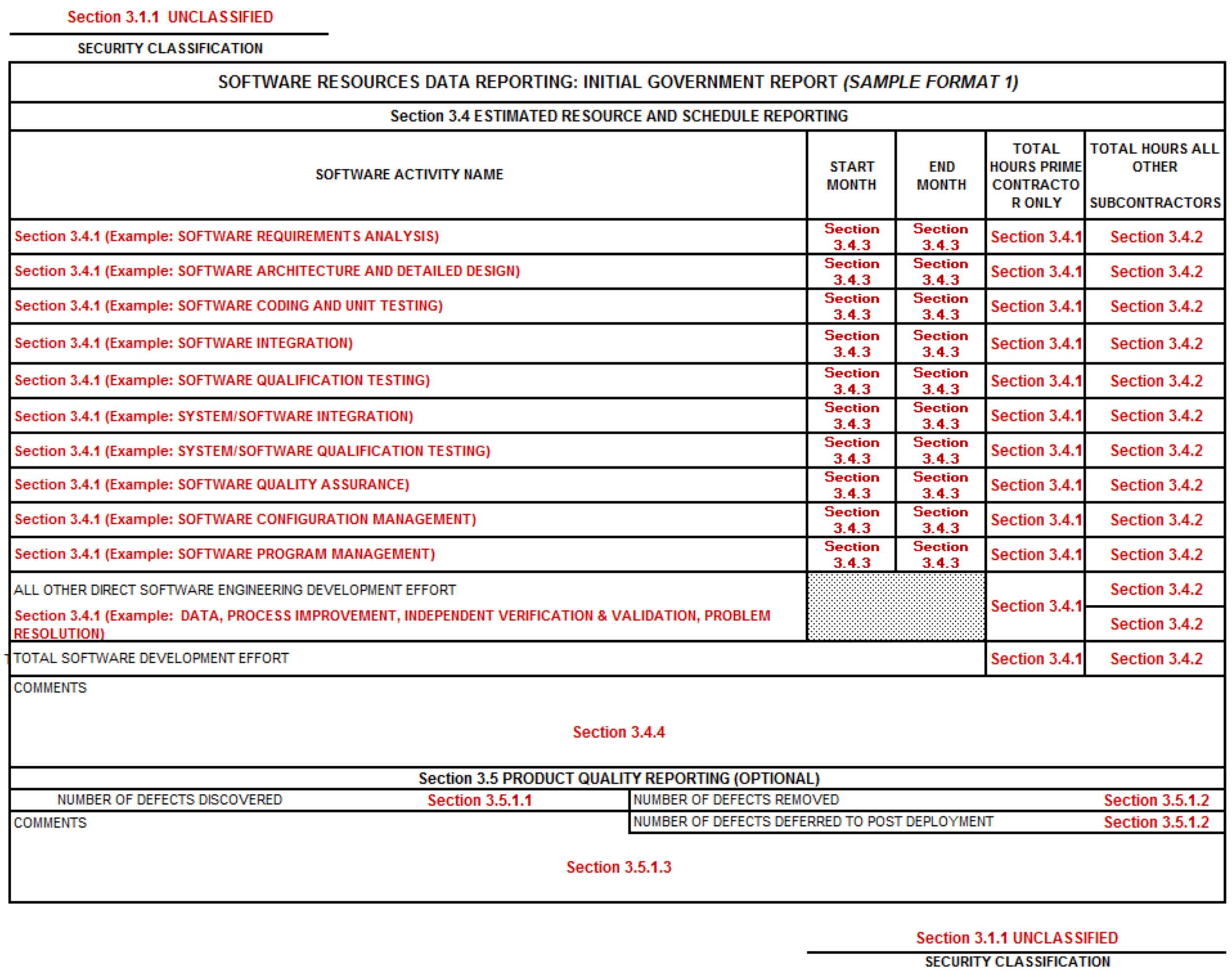
Section 3.2.6 PERSONNEL EXPERIENCE IN DOMAIN					
VERY HIGHLY EXPERIENCED:	Section 3.2.6 %	HIGHLY EXPERIENCED:	Section 3.2.6 %	NOMINALLY EXPERIENCED:	Section 3.2.6 %
LOW EXPERIENCE:	Section 3.2.6 %	INEXPERIENCED/ENTRY LEVEL:	Section 3.2.6 %		
COMMENTS	Section 3.2.7				

Section 3.3 ESTIMATED PRODUCT SIZE REPORTING						
NUMBER OF SOFTWARE REQUIREMENTS	TOTAL	Section 3.3.1.1	NUMBER OF EXTERNAL INTERFACE REQUIREMENTS	TOTAL	Section 3.3.2.1	REQUIREMENTS VOLATILITY Section 3.3.3
	NEW	Section 3.3.1.2		NEW	Section 3.3.2.2	

Section 3.3.4 ESTIMATED TOTAL DELIVERED CODE	COUNTING CONVENTION		PRIME CONTRACTOR ONLY	ALL OTHER SUBCONTRACTORS
Section 3.3.4.1 AMOUNT OF DELIVERED CODE DEVELOPED NEW	Section 3.3.4.2	HUMAN GENERATED	Section 3.3.4.1	Section 3.3.4.1
	Section 3.3.4.2	AUTO GENERATED	Section 3.3.4.1	Section 3.3.4.1
Section 3.3.4.1 AMOUNT OF DELIVERED CODE REUSED FROM EXTERNAL SOURCE (i.e., NOT INHERITED FROM PREVIOUS INCREMENT/BUILD OR PREDECESSOR)	Section 3.3.4.2	WITH MODIFICATIONS	Section 3.3.4.1	Section 3.3.4.1
	Section 3.3.4.2	WITHOUT MODIFICATIONS	Section 3.3.4.1	Section 3.3.4.1
Section 3.3.4.1 AMOUNT OF DELIVERED CODE INHERITED (i.e., REUSED FROM PREVIOUS INCREMENT/BUILD or PREDECESSOR)	Section 3.3.4.2	WITH MODIFICATIONS	Section 3.3.4.1	Section 3.3.4.1
	Section 3.3.4.2	WITHOUT MODIFICATIONS	Section 3.3.4.1	Section 3.3.4.1
		TOTAL DELIVERED CODE	Section 3.3.4.1	Section 3.3.4.1
COMMENTS	Section 3.3.5			

Section 3.1.1 UNCLASSIFIED
SECURITY CLASSIFICATION

Figure 10 SRDR Page 1 (bottom)



Section 3.1.1 UNCLASSIFIED

SECURITY CLASSIFICATION

SOFTWARE RESOURCES DATA REPORTING: INITIAL GOVERNMENT REPORT *(SAMPLE FORMAT 1)*

Section 3.4 ESTIMATED RESOURCE AND SCHEDULE REPORTING

SOFTWARE ACTIVITY NAME	START MONTH	END MONTH	TOTAL HOURS PRIME CONTRACTOR ONLY	TOTAL HOURS ALL OTHER SUBCONTRACTORS
Section 3.4.1 (Example: SOFTWARE REQUIREMENTS ANALYSIS)	Section 3.4.3	Section 3.4.3	Section 3.4.1	Section 3.4.2
Section 3.4.1 (Example: SOFTWARE ARCHITECTURE AND DETAILED DESIGN)	Section 3.4.3	Section 3.4.3	Section 3.4.1	Section 3.4.2
Section 3.4.1 (Example: SOFTWARE CODING AND UNIT TESTING)	Section 3.4.3	Section 3.4.3	Section 3.4.1	Section 3.4.2
Section 3.4.1 (Example: SOFTWARE INTEGRATION)	Section 3.4.3	Section 3.4.3	Section 3.4.1	Section 3.4.2
Section 3.4.1 (Example: SOFTWARE QUALIFICATION TESTING)	Section 3.4.3	Section 3.4.3	Section 3.4.1	Section 3.4.2
Section 3.4.1 (Example: SYSTEM/SOFTWARE INTEGRATION)	Section 3.4.3	Section 3.4.3	Section 3.4.1	Section 3.4.2
Section 3.4.1 (Example: SYSTEM/SOFTWARE QUALIFICATION TESTING)	Section 3.4.3	Section 3.4.3	Section 3.4.1	Section 3.4.2
Section 3.4.1 (Example: SOFTWARE QUALITY ASSURANCE)	Section 3.4.3	Section 3.4.3	Section 3.4.1	Section 3.4.2
Section 3.4.1 (Example: SOFTWARE CONFIGURATION MANAGEMENT)	Section 3.4.3	Section 3.4.3	Section 3.4.1	Section 3.4.2
Section 3.4.1 (Example: SOFTWARE PROGRAM MANAGEMENT)	Section 3.4.3	Section 3.4.3	Section 3.4.1	Section 3.4.2
ALL OTHER DIRECT SOFTWARE ENGINEERING DEVELOPMENT EFFORT Section 3.4.1 (Example: DATA, PROCESS IMPROVEMENT, INDEPENDENT VERIFICATION & VALIDATION, PROBLEM RESOLUTION)	▨	▨	Section 3.4.1	Section 3.4.2 Section 3.4.2
TOTAL SOFTWARE DEVELOPMENT EFFORT			Section 3.4.1	Section 3.4.2

COMMENTS

Section 3.4.4

Section 3.5 PRODUCT QUALITY REPORTING (OPTIONAL)

NUMBER OF DEFECTS DISCOVERED	Section 3.5.1.1	NUMBER OF DEFECTS REMOVED	Section 3.5.1.2
COMMENTS		NUMBER OF DEFECTS DEFERRED TO POST DEPLOYMENT	Section 3.5.1.2

Section 3.5.1.3

Section 3.1.1 UNCLASSIFIED

SECURITY CLASSIFICATION

Figure 11 SRDR Page 2

9.4.1 Proposed Modifications

In 2010, the modifications in Table 33 were proposed to the DCARC. Most of the recommendations were incorporated, to some degree, in the 2011 SRDR instructions. It will take several years before data appears with the addition data items.

The relevance of this section in this manual is for demonstrating that DCARC will evolve the SRDR to meet future information needs. SRDR users need to be proactive with the DCARC to express their needs for different types of data. The recommendations in Table 33were accompanied with examples of data analysis highlighting the shortfalls in the current data collection.

Table 33 Recommended SRDR Modifications

Current 2007 SRDR	Proposed Modifications	Rationale
Application Types (3.7.1 – 17)	• Reorganize around Operating Environments and Application Domains • Add Mission Criticality (add reliability and complexity in a single rating scale) • Revisit detailed definitions of the Application Domains	• Reduce duplication • Structure productivity analysis domains, database planning guidance • Account for productivity variations
Amount of New (>25%), Modified (<25% mod) Code	• Add DM, CM, IM, SU, & UNFM factors for modified code • Incorporate Galorath-like questionnaire • Add IM for reused code • Definitions for code types • Count at the level it will be maintained	• Improve derivation of equivalent SLOC for use in calibration and estimation • Excludes COTS; more accurate for generated code • Includes the code base for evolutionary acquisition
Deleted Code	• Report deleted code counts	• Deleting code does take effort
Software and External Interface Requirements	• Add anticipated requirements volatility to 2630-1, 2 • Use percentage of requirements change as volatility input (SRR baseline)	• CARD realism • Traceability • Improve calibration and estimation accuracy
Personnel Experience & Turnover	• Add to 2630-1 • Expand years of experience rating scale to 12 years	• CARD realism • Traceability • Improve calibration and estimation accuracy
Project- or CSCI-level data	• Specify the level of data reporting	• Apples-to-Apples comparison • Improved data analysis

Table 33 Recommended SRDR Modifications

Current 2007 SRDR	Proposed Modifications	Rationale
All Other Direct Software Engineering Development Effort (4.7): • Project Management • IV&V • Configuration Management • Quality Control • Problem Resolution • Library Management • Process Improvement • Measurement • Training • Documentation • Data Conversion • Customer-run Acceptance Test • Software Delivery, Installation & Deployment	Break into: • Management functions • Configuration / Environment functions • Assessment functions • Organization functions (e.g. user & maintainer documentation, measurement, training, process improvement, etc.)	• Improve calibration and estimation accuracy for different functions
Product Quality: • Mean Time To critical Defect (MTTD) • Analogy with Similar Systems	Are there better measures, e.g.: • Total number of priority 1, 2, 3, 4, & 5 defects discovered • Total number of priority 1, 2, 3, 4, & 5 defects removed	• There is limited quality information • If it is not going to be reported, why put it on the form?

9.5 MIL-STD-881C WBS Mapping to Productivity Types

The Work Breakdown Structures were adapted from MIL-STD-881C to assist in determining the correct Productivity Type (PT). Each System from 881C is listed with the associated one of more Metrics Manual Operating Environments.

Within the environments, look through the Subsystems to find one that matches the component being estimated. Each Subsystem or Sub-Subsystem has a matching PT.

Use the PT to lookup the associated Productivity-based CER and Model-based CER/SER.

9.5.1 Aerial Vehicle Manned (AVM)

Source: MIL-STD-881C Appendix-A: Aircraft Systems

Env	SubSystem	Sub-Subsystem	Domain	PT
AVM	Air Vehicle	Flight Control Subsystem	⇐	VC
		Auxiliary Power Subsystem	⇐	VC
		Hydraulic Subsystem	⇐	VC
		Electrical Subsystem	⇐	VC
		Crew Station Subsystem	⇐	VC
		Environmental Control Subsystem	⇐	VC
		Fuel Subsystem	⇐	VC
		Landing Gear	⇐	VC
		Rotor Group	⇐	VC
		Drive System	⇐	VC
AVM	Avionics	Communication / Identification	Intercoms	RTE
			Radio System(S)	RTE
			Identification Equipment (IFF)	RTE
			Data Links	RTE
		Navigation / Guidance	Radar	SCP
			Radio	SCP
			Other Essential Nav Equipment	RTE
			Radar Altimeter	SCP
			Direction Finding Set	RTE
			Doppler Compass	SCP
AVM	Avionics	Mission Computer / Processing	⇐	MP

Env	SubSystem	Sub-Subsystem	Domain	PT
AVM	Avionics	Fire Control	Search, Target, Tracking Sensors	SSP
			Self-Contained Navigation	RTE
			Self-Contained Air Data Systems	RTE
			Displays, Scopes, Or Sights	RTE
			Bombing Computer	MP
			Safety Devices	RTE
		Data Display and Controls	Multi-Function Displays	RTE
			Control Display Units	RTE
			Display Processors	MP
			On-Board Mission Planning	TRN
		Survivability	Ferret And Search Receivers	SCP
			Warning Devices	SCP
			Electronic Countermeasures	SCP
			Jamming Transmitters	SCP
			Chaff	SCP
			Infra-Red Jammers	SCP
			Terrain-Following Radar	SCP
		Reconnaissance	Photographic Sensors	SCP
			Electronic Sensors	SCP
			Infrared Sensors	SCP
			Search Receivers	SCP
			Recorders	SCP
			Warning Devices	SCP
			Magazines	RTE
			Data Link	RTE

Env	SubSystem	Sub-Subsystem	Domain	PT
AVM	Avionics	Automatic Flight Control	Flight Control Computers	MP
			Signal Processors	SCP
			Data Formatting	MP
			Interfaces To Other Systems	MP
			Pressure Transducers	SCP
			Rate Gyros	SCP
			Accelerometers	SCP
			Motion Sensors	SCP
		Health Monitoring System	⇐	SYS
		Stores Management	⇐	MP

9.5.2 Ordinance Vehicle Unmanned (OVU)

Source: MIL-STD-881C Appendix-C: Missile Systems

Env	SubSystem	Sub-Subsystem	Domain	PT
OVU	Air Vehicle	Guidance	Seeker Assembly	SCP
			Guidance Software	RTE
		Navigation	Sensor Assembly	SCP
			Navigation Software	RTE
		Payload	Target Defeat Mechanism	RTE
			Target Detection Device	SCP
			Fuze	SCP
			Payload-specific software	VP
		Power and Distribution	Primary Power	VC
			Power Conditioning Electronics	VC
			Power and distribution software	VC
		Communications	Antenna Assembly	SCP
			Communications software	RTE

Env	SubSystem	Sub-Subsystem	Domain	PT
OVU	Air Vehicle	Propulsion Subsystem	Motor Engine	VC
			Thrust Vector Actuation	VC
			Attitude Control System	VC
			Fuel / Oxidizer Liquid Management	VC
			Arm / Fire Device	VC
			Flight Termination/Mission Termination	RTE
			Propulsion software	VC
OVU	Air Vehicle	Controls	Controls software	VC
		Reentry System	⇐	VC
		Post boost System	⇐	VC
		On Board Test Equipment	⇐	TST
		On Board Training Equipment	⇐	TRN
		Auxiliary Equipment	⇐	SYS
		Air Vehicle Software	⇐	MP
OVU	Encasement Device	Encasement Device Software	⇐	MP
OVU	Command & Launch	Surveillance, Identification, and Tracking Sensors	⇐	SCP
		Launch & Guidance Control	⇐	RTE
		Communications	⇐	RTE
		Launcher Equipment	⇐	RTE
		Auxiliary Equipment	⇐	SYS

9.5.3 Ordinance Vehicle Unmanned (OVU)

Source: MIL-STD-881C Appendix-D: Ordinance Systems

Env	SubSystem	Sub-Subsystem	Domain	PT
OVU	Munition	Guidance	Seeker Assembly	SCP
			Guidance Software	RTE
		Navigation	Sensor Assembly	SCP
			Navigation Software	RTE
OVU	Munition	Payload	Target Defeat Mechanism	RTE
			Target Detection Device	SCP
			Fuze	SCP
			Payload software	VP
OVU	Munition	Power and Distribution	Primary Power	VC
			Power Conditioning Electronics	VC
			Power and distribution software	VC
OVU	Munition	Communications	Antenna Assembly	SCP
			Communications software	RTE
OVU	Munition	Propulsion Subsystem	Motor Engine	VC
			Fuel / Oxidizer Liquid Management	VC
			Arm / Fire Device	VC
			Thrust Vector Actuation	VC
			Flight Termination/Mission Termination	RTE
			Propulsion software	VC
OVU	Munition	Controls	Controls software	VC
		On Board Test Equipment	⇐	TST
		On Board Training Equipment	⇐	TRN
		Auxiliary Equipment	⇐	SYS
		Munition Software	⇐	MP
	Launch System	Fire Control	⇐	RTE

9.5.4 Maritime Vessel Manned (MVM)

Source: MIL-STD-881C Appendix-E: Sea Systems

Env	SubSystem	Sub-Subsystem	Domain	PT
MVM	Ship	Command, Communication & Surveillance	Sensing and data	RTE
			Navigation equipment	RTE
			Interior communication	RTE
			Gun fire control system	RTE
			Non-electronic & electronic countermeasure	RTE
MVM	Ship	Command, Communication & Surveillance	Missile fire control systems	RTE
			Antisubmarine warfare fire control and torpedo fire control systems	RTE
			Radar systems	RTE
			Radio communication systems	RTE
			Electronic navigation systems	RTE
			Space vehicle electronic tracking systems	RTE
			Sonar systems	RTE
			Electronic tactical data systems	MP
			Fiber optic plant	BIS
			Inter / intranet	BIS
			Entertainment systems	BIS

9.5.5 Space Vehicle Manned / Unmanned (SVM/U) and Ground Site Fixed (GSF)

Source: MIL-STD-881C Appendix-F: Space Systems

Env	SubSystem	Sub-Subsystem	Domain	PT
SVM/U	Bus	Structures & Mechanisms (SMS)	⇐	VC
		Thermal Control (TCS)	⇐	VC
		Electrical Power (EPS)	⇐	VC
		Attitude Control (ACS)	⇐	VC
		Propulsion	⇐	VC
		Telemetry, Tracking, & Command (TT&C)	⇐	RTE
		Bus Flight Software	⇐	MP
SVM/U	Payload	Thermal Control	⇐	RTE
		Electrical Power	⇐	RTE
		Pointing, Command, & Control Interface	⇐	VP
		Payload Antenna	⇐	SCP
		Payload Signal Electronics	⇐	SCP
		Optical Assembly	⇐	SCP
		Sensor	⇐	SCP
		Payload Flight Software	⇐	VP
GSF	Ground Operations & Processing Center	Mission Management	⇐	BIS
		Command and Control	⇐	C&C
		Mission Data Processing	⇐	BIS
		Mission Data Analysis	⇐	BIS
		Collection Management	⇐	BIS
		Infrastructure & Framework	⇐	SYS
GSF	Ground Terminal / Gateway	Ground Terminal Software	Application Specific Integrated Circuit	SCP
			Field Programmable Gate Array	SCP

9.5.6 Ground Vehicle Manned and Unmanned (GVM/U)

Source: MIL-STD-881C Appendix-G: Surface Vehicle Systems

Env	SubSystem	Sub-Subsystem	Domain	PT
GVM/U	Primary Vehicle	System Survivability	⇐	
		Turret Assembly	⇐	RTE
		Suspension / Steering	⇐	SCP
GVM/U	Primary Vehicle	Vehicle Electronics	Computers And Other Devices For Command And Control	VC
			Data Control And Distribution	MP
			Controls And Displays	BIS
			Power Distribution And Management	RTE
			Health Management Systems	RTE

Env	SubSystem	Sub-Subsystem	Domain	PT
GVM/U	Primary Vehicle	Power Package / Drive Train	Controls And Instrumentation	VC
			Power Transmission, Final Drivers, And Power Takeoffs	VC
			Brakes And Steering When Integral To Power Transmission	VC
			Hybrid Electric Drive Systems	VC
			Energy Storage Systems	VC
		Fire Control	Radars And Other Sensors	SCP
			Controls And Displays	RTE
			Sights Or Scopes	RTE
			Range Finders, Gun Drives And Stabilization Systems	RTE
		Armament	Main Gun And Secondary Guns	VP
			Missile Launchers	VP
			Non-Lethal Weapons	VP
			Other Offensive Weapon Systems	VP
		Automatic Ammunition Handling	⇐	MP
	Primary Vehicle	Navigation and Remote Piloting	⇐	RTE
		Communications	⇐	RTE
GVU	Remote Control System (UGV specific)	Ground Control Systems	⇐	RTE
		Command and Control Subsystem	⇐	C&C
		Remote Control System Software	⇐	RTE

9.5.7 Aerial Vehicle Unmanned(AVU) & Ground Site Fixed (GSF)

Source: MIL-STD-881C Appendix-H: Unmanned Air Vehicle Systems

Env	SubSystem	Sub-Subsystem	Domain	PT
AVU	Air Vehicle	Vehicle Subsystems	Propulsion	VC
			Flight Control Subsystem	VC
			Auxiliary Power Subsystem	VC
			Hydraulic Subsystem	VC
			Electrical Subsystem	VC
			Environmental Control	VC
			Subsystem Fuel Subsystem	VC
			Landing Gear	VC
			Rotor Group	VC
			Drive System	VC
AVU	Air Vehicle	Avionics	Communication / Identification	RTE
			Navigation / Guidance	RTE
			Automatic Flight Control	VC
			Health Monitoring System	SYS
			Stores Management	VP
			Mission Processing	MP
			Fire Control	RTE
AVU	Payload	Survivability Payload	⇐	VP
		Reconnaissance Payload	⇐	VP
		Electronic Warfare Payload	⇐	VP
		Armament / Weapons Delivery	⇐	VP
GSF	Ground / Host Segment	Ground Control Systems	⇐	C&C
		Command and Control Subsystem	⇐	RTE
		Launch and Recovery Equipment	⇐	RTE

9.5.8 Maritime Vessel Unmanned (MVU) and Maritime Vessel Manned (MVM)

Source: MIL-STD-881C Appendix-I: Unmanned Maritime Vessel Systems

Env	SubSystem	Sub-Subsystem	Domain	PT
UMV	Maritime Vehicle	Energy Storage / Conversion	Energy Storage And Conversion Monitoring And Control System	VC
		Electrical Power	Electric Power Monitoring And Control System	VC
		Vehicle Command and Control	Mission Control	RTE
			Navigation	RTE
			Guidance And Control	RTE
			Health Status Monitoring	SYS
			Rendezvous, Homing And Docking Systems	SYS
			Fire Control	RTE
		Surveillance	⇐	RTE
		Communications / Identification	⇐	RTE
		Ship Control Systems	Hovering And Depth Control	VC
			Ballast And Trim	VC
			Maneuvering System	VC
		Auxiliary Systems	Emergency Systems	MP
			Launch And Recovery System	MP
			Environmental Control System	MP
			Anchoring, Mooring And Towing	MP
			Miscellaneous Fluid Systems	MP
	Payload	Survivability Payload	⇐	VP
		Intelligence, Surveillance Reconnaissance Payload	⇐	VP
		Armament / Weapons Delivery Payload	⇐	VP
		Mission Payload	⇐	VP

Env	SubSystem	Sub-Subsystem	Domain	PT
MVM	Shipboard Segment	Shipboard UM Command and Control Subsystem	⇐	C&C
		Shipboard Communication Subsystem	⇐	RTE
		Shipboard Power Subsystem	⇐	VC
		Launch and Recovery Equipment	⇐	RTE

9.5.9 Ordinance Vehicle Unmanned (OVU)

Source: MIL-STD-881C Appendix-J: Launch Vehicles

Env	SubSystem	Sub-Subsystem	Domain	PT
OVU	Launch Vehicle	Stage(s)	Propulsions System	VC
			Reaction Control System	VC
			Recovery System	VC
			Environmental Control System	RTE
			Stage Peculiar Avionics	RTE
		Avionics	Guidance Navigation and Control	RTE
			Power	VC
			Data Acquisition and Telemetry	RTE
			Range Tracking & Safety (Airborne)	RTE
			Flight Software	VC
	Flight Operations	Real-time mission control	Telemetry processing	RTE
			Communications	RTE
			Data reduction and analysis	BIS

9.5.10 Ground Site Fixed (GSF)

Source: MIL-STD-881C Appendix-K: Automated Information Systems

Env	SubSystem	Sub-Subsystem	Domain	PT
GSF	Custom Application Software	Subsystem Software CSCI	⇐	Variable
	Enterprise Service Element	Software COTS / GOTS	Component identification	BIS
			Assessment and Selection	BIS
			Prototyping	BIS
			Glue code development	BIS
			Tailoring and configuration	BIS
	Enterprise Information System	Business Software COTS / GOTS	Component identification	BIS
			Assessment and Selection	BIS
			Prototyping	BIS
			Glue code development	BIS
			Tailoring and configuration	BIS

9.5.11 Applies to ALL Environments

Source: MIL-STD-881C Appendix-L: Common Elements

Env	SubSystem	Sub-Subsystem	Domain	PT
CE	System Integration Lab (SIL)	SIL Software - SIL Operations	⇐	TST
		SIL Software - Simulation	⇐	SCI
	Test and Evaluation Support	Test Software	⇐	STS
	Automated Test Equipment	Equipment Software	⇐	TST
	Training	Equipment	⇐	TRN
		Simulators	⇐	SCI
		Computer Based-Application	⇐	BIS
		Computer Based-Web	⇐	BIS
	Support Equipment	Software	⇐	BIS
	Test and Measurement Equipment	Equipment Software	⇐	TST
	Data Migration	Software Utilities	⇐	BIS

9.6 Productivity (Pr) Benchmark Details

9.6.1 Normality Tests on Productivity Data

Before analyzing the data for central tendencies, a check was made of the normality of each dataset that had five (5) or more records using the Anderson-Darling Normality Test. To reject the hypothesis of normality, the Anderson-Darling statistic, A^2, needs to exceed the critical value of 0.787 for the case when the mean and variance are unknown. Additionally, if the P value is less than the level of significance, 0.05 in this case, the hypothesis of normality is rejected.

In plain English, the dataset distribution is normally distributed if:

- A^2 is less than 0.787
- P-value is greater than the level of significance (0.05)
- In the event of a tie, visually inspect the distribution with a normal curve overlay

For each dataset that fails the normality test, a Box-Cox transform was used to determine the function, F_t, required to transform the data into a more normal-like distribution thereby improving the validity of the measurement of the mean and median.

Table 34, Table 35and Table 36 show the results of the Anderson-Darling test on productivity data grouped by Operating Environments (OpEnv), Productivity Types (PT) and OpEnv-PT pairs. The table columns are:

- Group name
- N: number of records
- $A^{2:}$: Anderson-Darling test statistic
- P: P value
- F_t: function for transforming data to a more normal-like distribution, if required

To be included in the analysis, there were five (5) or more records in a group.

9.6.1.1 Operating Environments (all Productivity Types)

Table 34 OpEnv Productivity Normality Tests

	Operating Environment (OpEnv)	N	A^2	P	F_t
1	Aerial Vehicle Manned (AVM)	50	1.27	0.005	$X^{0.5}$
2	Ground Site Fixed (GFS)	116	0.95	0.016	$X^{0.5}$
3	Maritime Vessel Manned (MVM)	69	2.45	0.005	$X^{0.5}$
4	Ordinance Vehicle Unmanned (OVU)	16	0.42	0.285	Not Required
5	Space Vehicle Unmanned (SVU)	6	0.22	0.702	Not Required

9.6.1.2 Productivity Types (all Operating Environments)

Table 35 PT Productivity Normality Tests

	Productivity Type (PT)	N	A^2	P	F_t
1	Intel and Information Processing (IIS)	35	0.53	0.162	Log_e
2	Mission Processing (MP)	47	0.59	0.117	Log_e
3	Real-Time Embedded (RTE)	53	0.17	0.927	Log_e
4	Scientific Systems (SCI)	39	0.76	0.044	$x^{1.5}$
5	Sensor Control and Signal Processing (SCP)	38	0.62	0.100	Not Required
6	System Software (SYS)	60	0.30	0.566	Not Required

9.6.1.3 Operating Environment – Productivity Type Sets

To be included in the analysis, there has to be five (5) or more records in the OpEnv-PT pair. This caused some operating environments and productivity types to drop out of consideration.

Table 36 OpEnv - PT Normality Tests

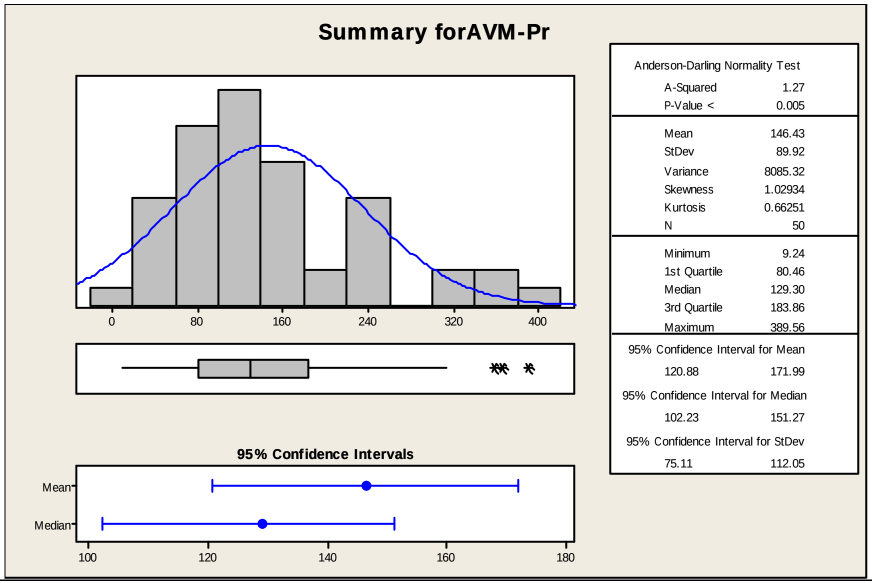
	OpEnv - PT	N	A^2	P	F_t
1	AVM-MP	31	1.89	0.005	Log_e
2	AVM-RTE	9	0.832	0.019	Log_e
3	AVM-SCP	8	0.227	0.725	Not Required
4	GSF-IIS	23	0.44	0.274	Not Required
5	GSF-MP	6	0.23	0.661	Not Required
6	GSF-RTE	23	0.41	0.310	Not Required
7	GSF-SCI	23	0.95	0.013	X^2
8	GSF-SCP	13	0.86	0.020	X^2
9	GSF-SYS	28	0.30	0.571	Not Required
10	MVM-MP	8	0.44	0.200	Not Required
11	MVM-RTE	6	0.58	0.074	Log_e
12	MVM-SCI	15	0.54	0.141	Not Required
13	MVM-SCP	7	0.43	0.217	Not Required
14	MVM-SYS	28	0.53	0.159	Not Required
15	OVU-RTE	11	0.27	0.593	Not Required

9.6.2 Statistical Summaries on Productivity Data

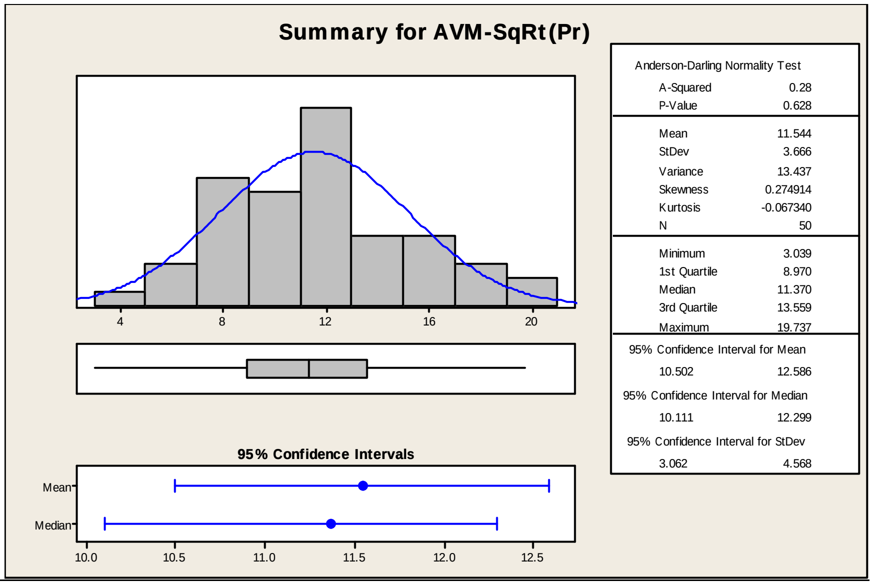
The following sections show statistical summaries of the non-transformed and, if required, the transformed productivity data. The transformation function, F_t, is shown in the summary table above the histogram.

9.6.2.1 Operating Environments

Non-Transformed	Transformed with F_t

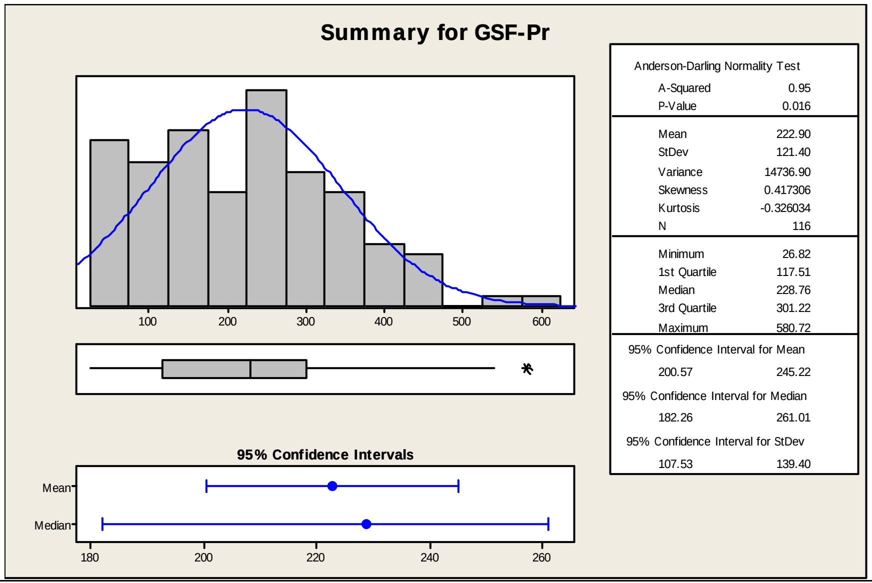


Anderson-Darling Normality Test	
A-Squared	1.27
P-Value <	0.005
Mean	146.43
StDev	89.92
Variance	8085.32
Skewness	1.02934
Kurtosis	0.66251
N	50
Minimum	9.24
1st Quartile	80.46
Median	129.30
3rd Quartile	183.86
Maximum	389.56
95% Confidence Interval for Mean	
120.88	171.99
95% Confidence Interval for Median	
102.23	151.27
95% Confidence Interval for StDev	
75.11	112.05

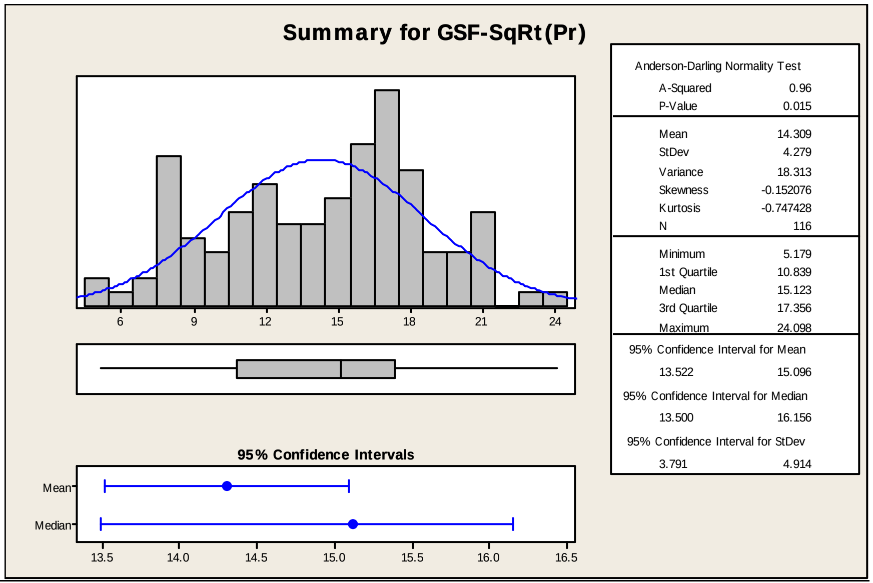


Anderson-Darling Normality Test	
A-Squared	0.28
P-Value	0.628
Mean	11.544
StDev	3.666
Variance	13.437
Skewness	0.274914
Kurtosis	-0.067340
N	50
Minimum	3.039
1st Quartile	8.970
Median	11.370
3rd Quartile	13.559
Maximum	19.737
95% Confidence Interval for Mean	
10.502	12.586
95% Confidence Interval for Median	
10.111	12.299
95% Confidence Interval for StDev	
3.062	4.568

Non-Transformed	Transformed with F_t

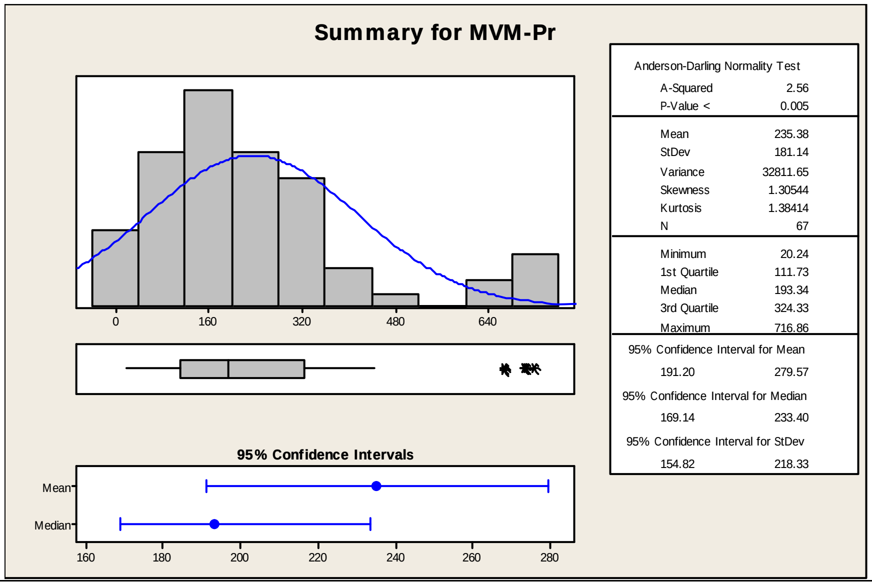


Anderson-Darling Normality Test	
A-Squared	0.95
P-Value	0.016
Mean	222.90
StDev	121.40
Variance	14736.90
Skewness	0.417306
Kurtosis	-0.326034
N	116
Minimum	26.82
1st Quartile	117.51
Median	228.76
3rd Quartile	301.22
Maximum	580.72
95% Confidence Interval for Mean	
200.57	245.22
95% Confidence Interval for Median	
182.26	261.01
95% Confidence Interval for StDev	
107.53	139.40

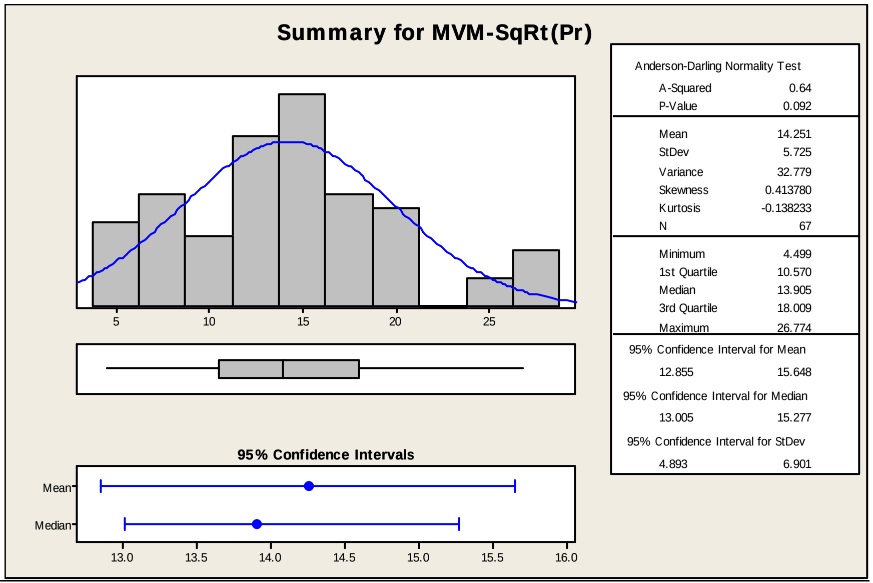


Anderson-Darling Normality Test	
A-Squared	0.96
P-Value	0.015
Mean	14.309
StDev	4.279
Variance	18.313
Skewness	-0.152076
Kurtosis	-0.747428
N	116
Minimum	5.179
1st Quartile	10.839
Median	15.123
3rd Quartile	17.356
Maximum	24.098
95% Confidence Interval for Mean	
13.522	15.096
95% Confidence Interval for Median	
13.500	16.156
95% Confidence Interval for StDev	
3.791	4.914

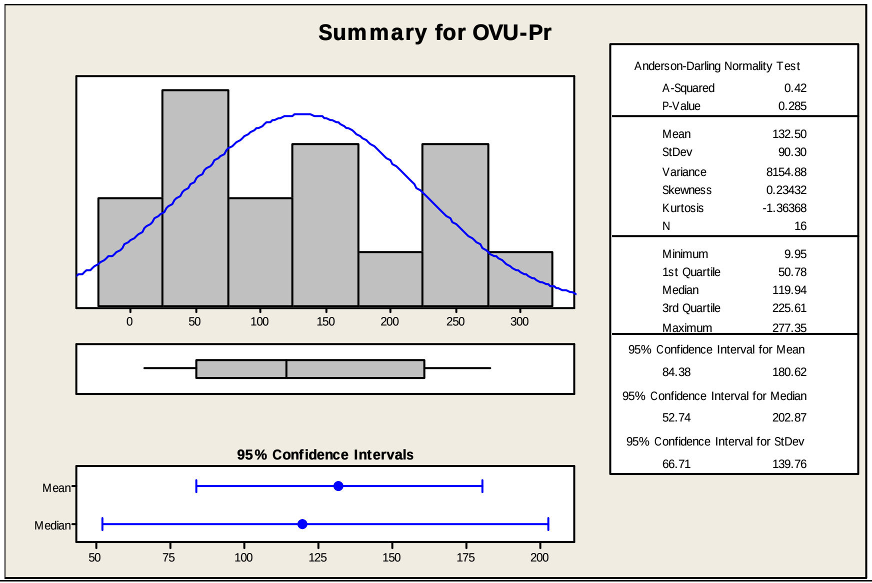
Non-Transformed	Transformed with F_t



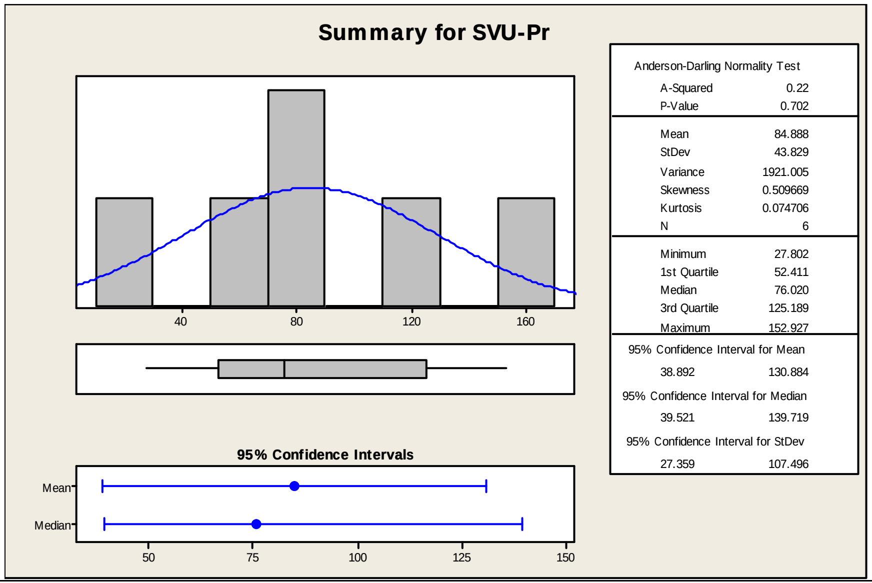
Anderson-Darling Normality Test	
A-Squared	2.56
P-Value <	0.005
Mean	235.38
StDev	181.14
Variance	32811.65
Skewness	1.30544
Kurtosis	1.38414
N	67
Minimum	20.24
1st Quartile	111.73
Median	193.34
3rd Quartile	324.33
Maximum	716.86
95% Confidence Interval for Mean	
191.20	279.57
95% Confidence Interval for Median	
169.14	233.40
95% Confidence Interval for StDev	
154.82	218.33



Anderson-Darling Normality Test	
A-Squared	0.64
P-Value	0.092
Mean	14.251
StDev	5.725
Variance	32.779
Skewness	0.413780
Kurtosis	-0.138233
N	67
Minimum	4.499
1st Quartile	10.570
Median	13.905
3rd Quartile	18.009
Maximum	26.774
95% Confidence Interval for Mean	
12.855	15.648
95% Confidence Interval for Median	
13.005	15.277
95% Confidence Interval for StDev	
4.893	6.901

Non-Transformed	Transformed with F_t
	Not Required

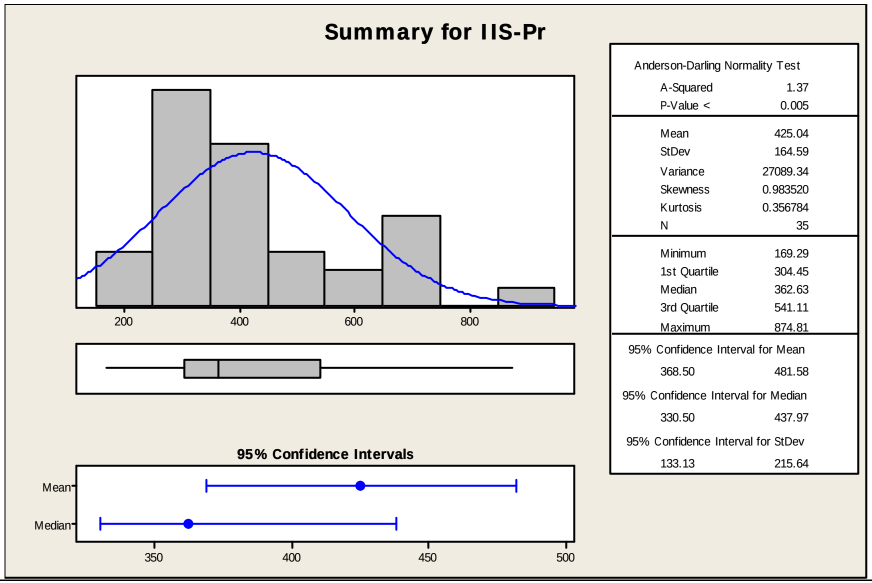
Anderson-Darling Normality Test	
A-Squared	0.42
P-Value	0.285
Mean	132.50
StDev	90.30
Variance	8154.88
Skewness	0.23432
Kurtosis	-1.36368
N	16
Minimum	9.95
1st Quartile	50.78
Median	119.94
3rd Quartile	225.61
Maximum	277.35
95% Confidence Interval for Mean	
84.38	180.62
95% Confidence Interval for Median	
52.74	202.87
95% Confidence Interval for StDev	
66.71	139.76

Non-Transformed	Transformed with F_t
	Not Required

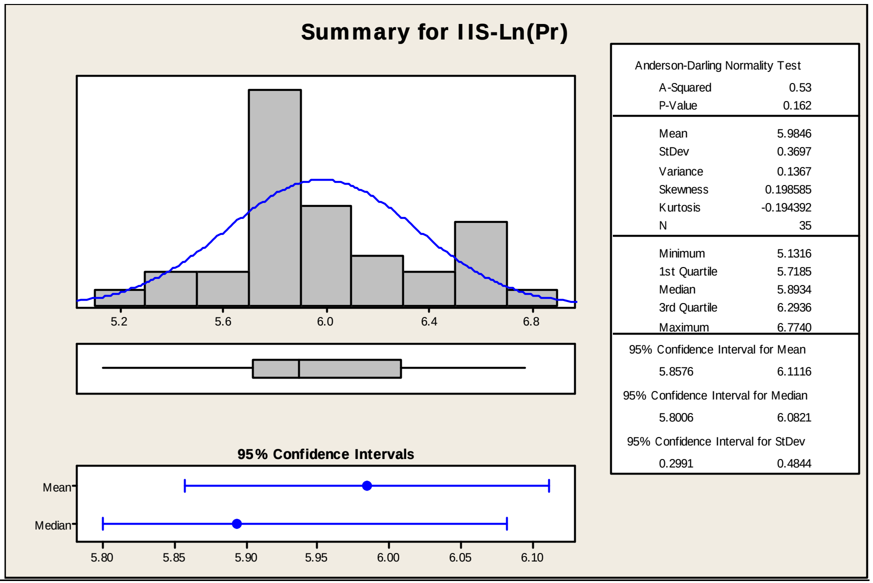
Anderson-Darling Normality Test	
A-Squared	0.22
P-Value	0.702
Mean	84.888
StDev	43.829
Variance	1921.005
Skewness	0.509669
Kurtosis	0.074706
N	6
Minimum	27.802
1st Quartile	52.411
Median	76.020
3rd Quartile	125.189
Maximum	152.927
95% Confidence Interval for Mean	
38.892	130.884
95% Confidence Interval for Median	
39.521	139.719
95% Confidence Interval for StDev	
27.359	107.496

9.6.2.2 Productivity Types

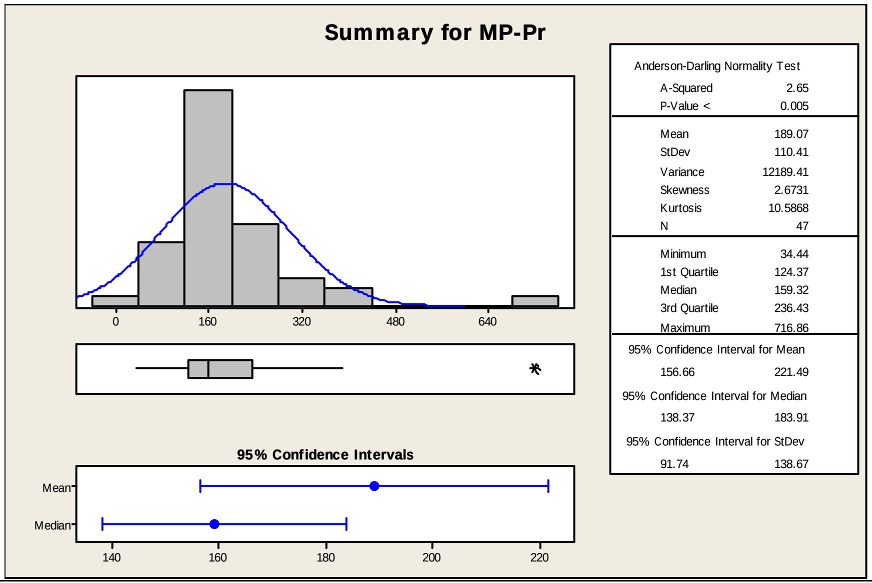
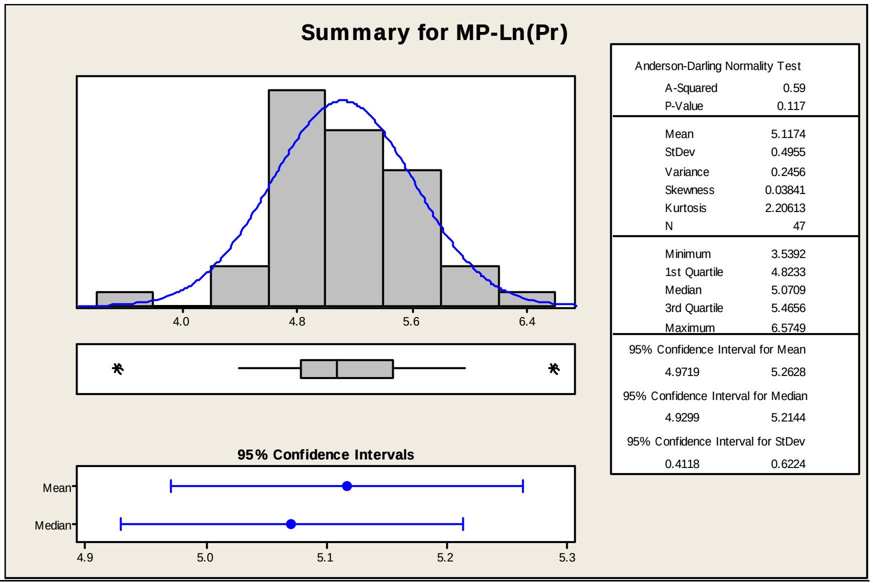
Non-Transformed	Transformed with F_t



Anderson-Darling Normality Test	
A-Squared	1.37
P-Value <	0.005
Mean	425.04
StDev	164.59
Variance	27089.34
Skewness	0.983520
Kurtosis	0.356784
N	35
Minimum	169.29
1st Quartile	304.45
Median	362.63
3rd Quartile	541.11
Maximum	874.81
95% Confidence Interval for Mean	
368.50	481.58
95% Confidence Interval for Median	
330.50	437.97
95% Confidence Interval for StDev	
133.13	215.64



Anderson-Darling Normality Test	
A-Squared	0.53
P-Value	0.162
Mean	5.9846
StDev	0.3697
Variance	0.1367
Skewness	0.198585
Kurtosis	-0.194392
N	35
Minimum	5.1316
1st Quartile	5.7185
Median	5.8934
3rd Quartile	6.2936
Maximum	6.7740
95% Confidence Interval for Mean	
5.8576	6.1116
95% Confidence Interval for Median	
5.8006	6.0821
95% Confidence Interval for StDev	
0.2991	0.4844

Non-Transformed	Transformed with F_t
	

Anderson-Darling Normality Test

A-Squared	2.65
P-Value <	0.005
Mean	189.07
StDev	110.41
Variance	12189.41
Skewness	2.6731
Kurtosis	10.5868
N	47
Minimum	34.44
1st Quartile	124.37
Median	159.32
3rd Quartile	236.43
Maximum	716.86

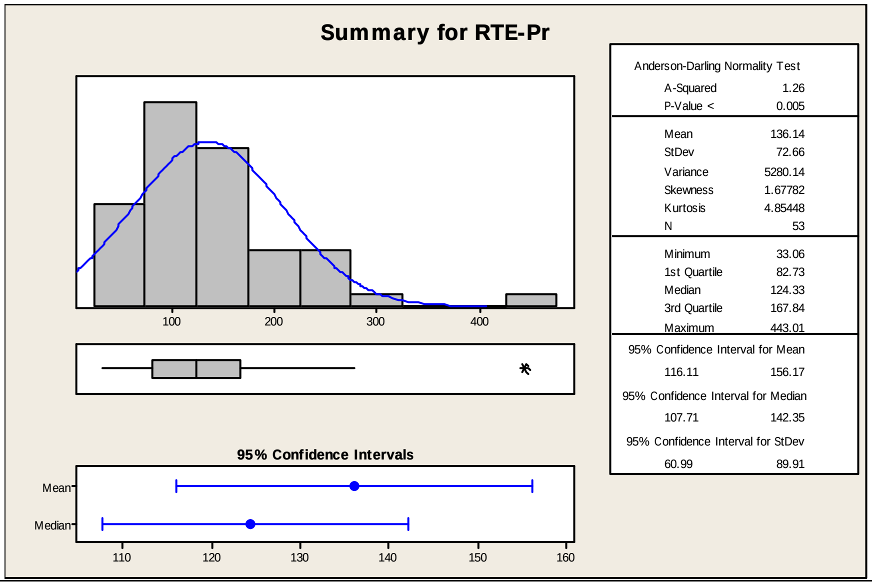
95% Confidence Interval for Mean	
156.66	221.49
95% Confidence Interval for Median	
138.37	183.91
95% Confidence Interval for StDev	
91.74	138.67

Anderson-Darling Normality Test

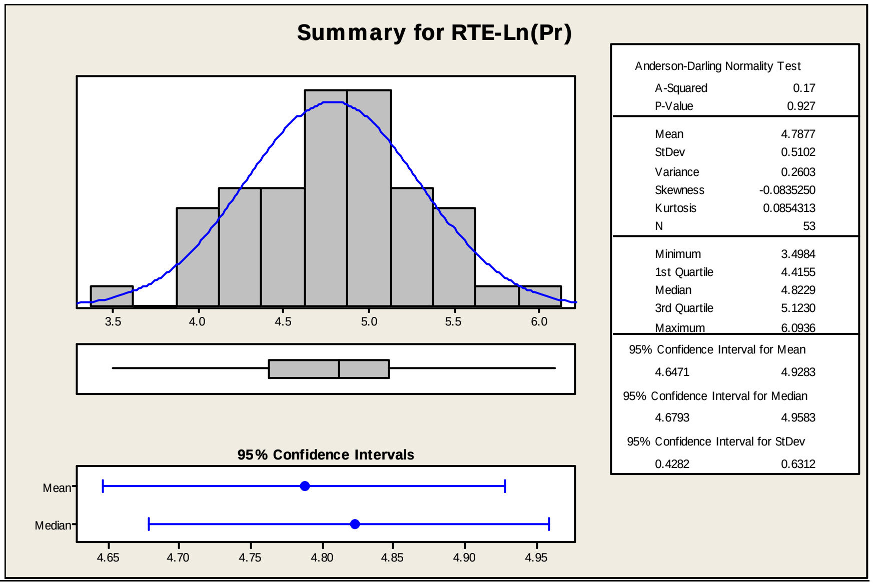
A-Squared	0.59
P-Value	0.117
Mean	5.1174
StDev	0.4955
Variance	0.2456
Skewness	0.03841
Kurtosis	2.20613
N	47
Minimum	3.5392
1st Quartile	4.8233
Median	5.0709
3rd Quartile	5.4656
Maximum	6.5749

95% Confidence Interval for Mean	
4.9719	5.2628
95% Confidence Interval for Median	
4.9299	5.2144
95% Confidence Interval for StDev	
0.4118	0.6224

Non-Transformed	Transformed with F_t

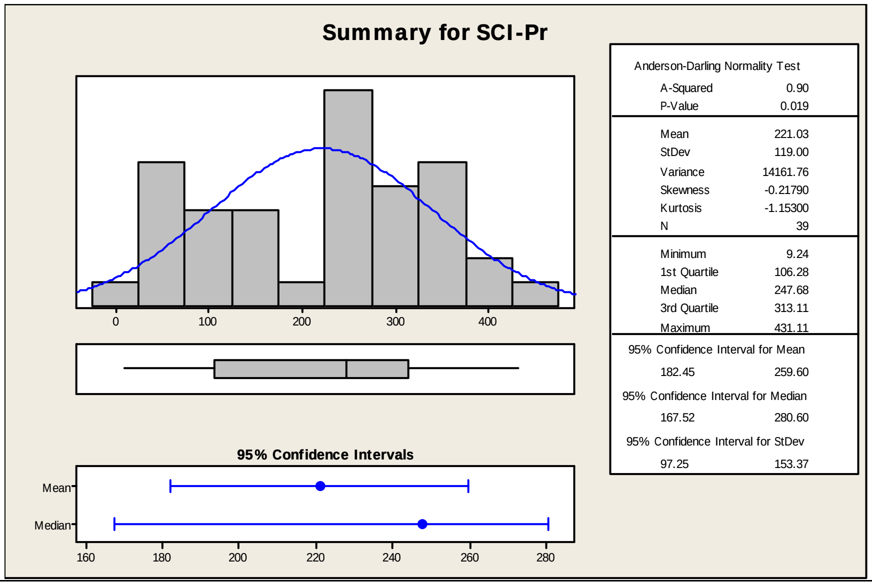


Anderson-Darling Normality Test	
A-Squared	1.26
P-Value <	0.005
Mean	136.14
StDev	72.66
Variance	5280.14
Skewness	1.67782
Kurtosis	4.85448
N	53
Minimum	33.06
1st Quartile	82.73
Median	124.33
3rd Quartile	167.84
Maximum	443.01
95% Confidence Interval for Mean	
116.11	156.17
95% Confidence Interval for Median	
107.71	142.35
95% Confidence Interval for StDev	
60.99	89.91

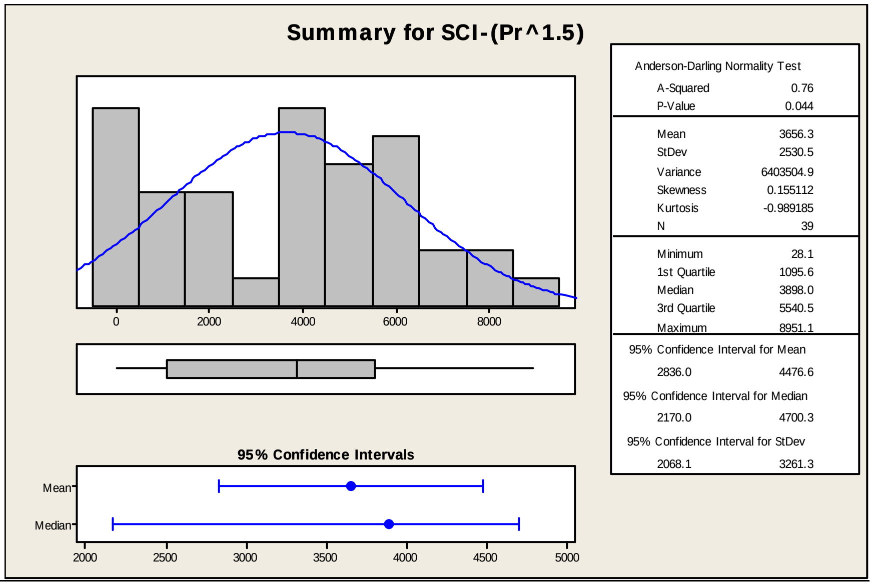


Anderson-Darling Normality Test	
A-Squared	0.17
P-Value	0.927
Mean	4.7877
StDev	0.5102
Variance	0.2603
Skewness	-0.0835250
Kurtosis	0.0854313
N	53
Minimum	3.4984
1st Quartile	4.4155
Median	4.8229
3rd Quartile	5.1230
Maximum	6.0936
95% Confidence Interval for Mean	
4.6471	4.9283
95% Confidence Interval for Median	
4.6793	4.9583
95% Confidence Interval for StDev	
0.4282	0.6312

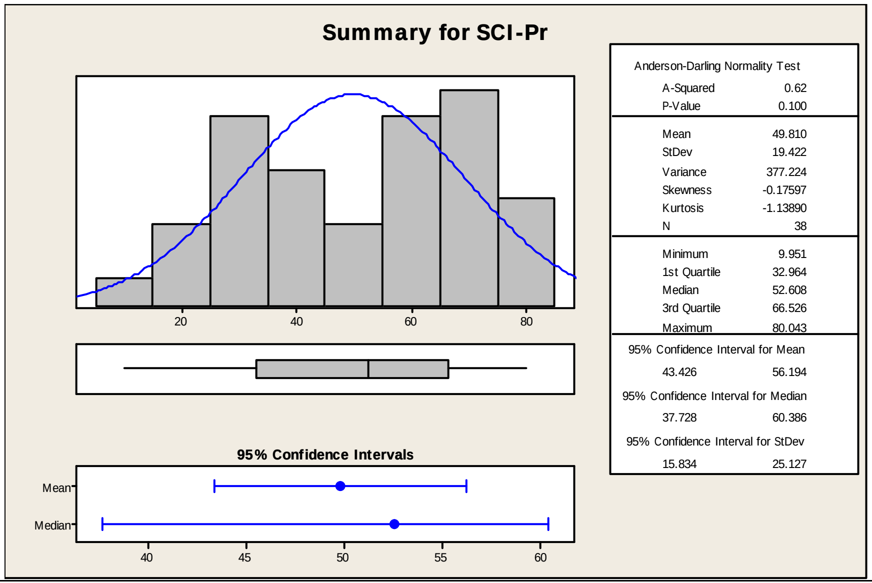
Non-Transformed	Transformed with F_t



Anderson-Darling Normality Test	
A-Squared	0.90
P-Value	0.019
Mean	221.03
StDev	119.00
Variance	14161.76
Skewness	-0.21790
Kurtosis	-1.15300
N	39
Minimum	9.24
1st Quartile	106.28
Median	247.68
3rd Quartile	313.11
Maximum	431.11
95% Confidence Interval for Mean	
182.45	259.60
95% Confidence Interval for Median	
167.52	280.60
95% Confidence Interval for StDev	
97.25	153.37

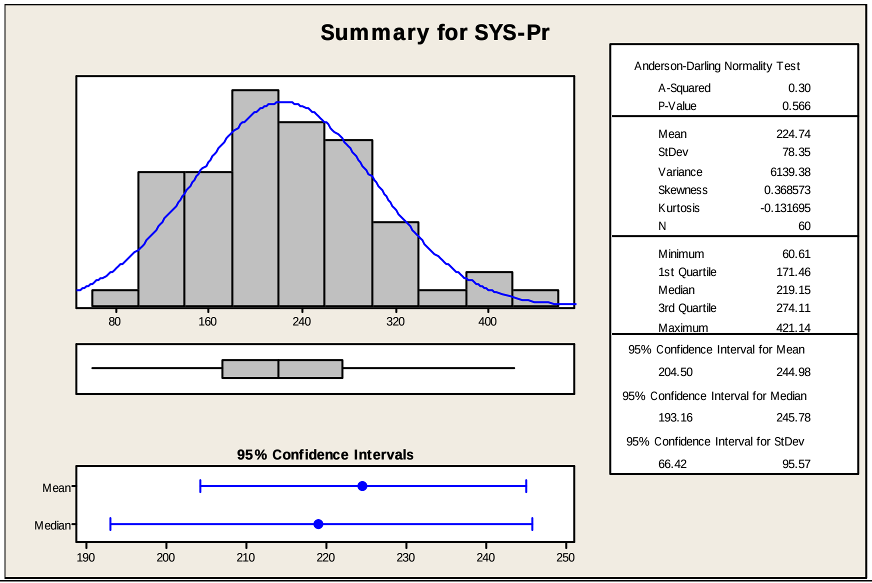


Anderson-Darling Normality Test	
A-Squared	0.76
P-Value	0.044
Mean	3656.3
StDev	2530.5
Variance	6403504.9
Skewness	0.155112
Kurtosis	-0.989185
N	39
Minimum	28.1
1st Quartile	1095.6
Median	3898.0
3rd Quartile	5540.5
Maximum	8951.1
95% Confidence Interval for Mean	
2836.0	4476.6
95% Confidence Interval for Median	
2170.0	4700.3
95% Confidence Interval for StDev	
2068.1	3261.3

Non-Transformed	Transformed with F_t
	Not Required

Summary for SCI-Pr

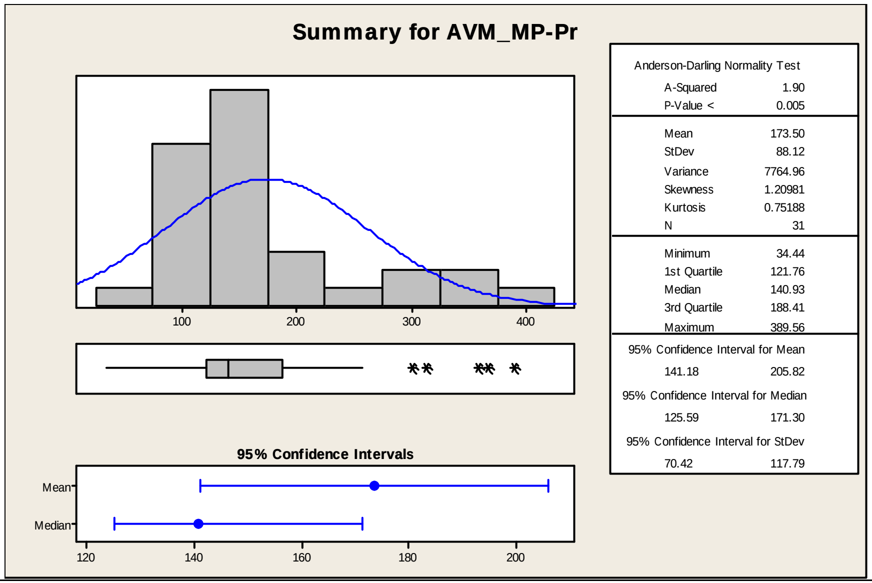
Anderson-Darling Normality Test	
A-Squared	0.62
P-Value	0.100
Mean	49.810
StDev	19.422
Variance	377.224
Skewness	-0.17597
Kurtosis	-1.13890
N	38
Minimum	9.951
1st Quartile	32.964
Median	52.608
3rd Quartile	66.526
Maximum	80.043
95% Confidence Interval for Mean	
43.426	56.194
95% Confidence Interval for Median	
37.728	60.386
95% Confidence Interval for StDev	
15.834	25.127

Non-Transformed	Transformed with F_t
	Not Required

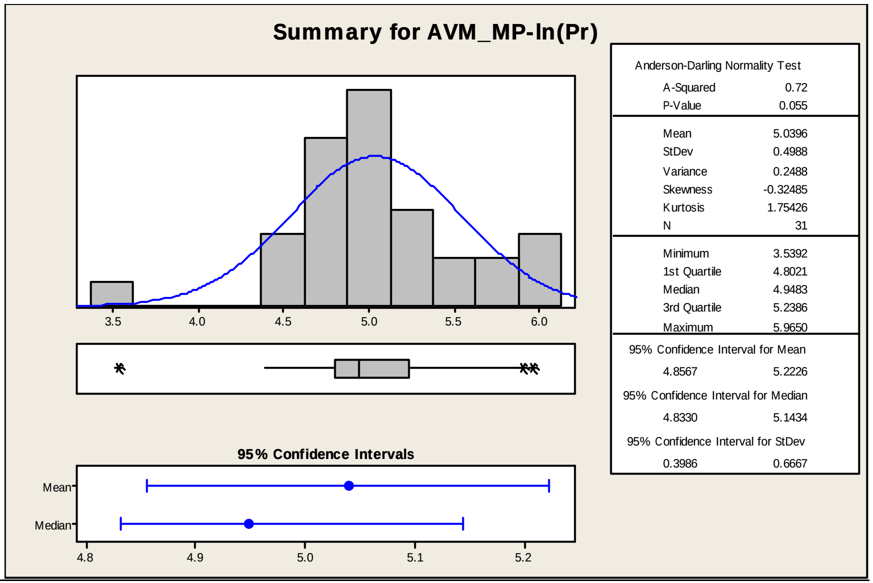
```
Anderson-Darling Normality Test
   A-Squared          0.30
   P-Value           0.566

   Mean             224.74
   StDev             78.35
   Variance        6139.38
   Skewness       0.368573
   Kurtosis      -0.131695
   N                    60

   Minimum           60.61
   1st Quartile     171.46
   Median           219.15
   3rd Quartile     274.11
   Maximum          421.14
 95% Confidence Interval for Mean
   204.50           244.98
95% Confidence Interval for Median
   193.16           245.78
 95% Confidence Interval for StDev
   66.42             95.57
```

9.6.2.3 Operating Environment - Productivity Type Sets

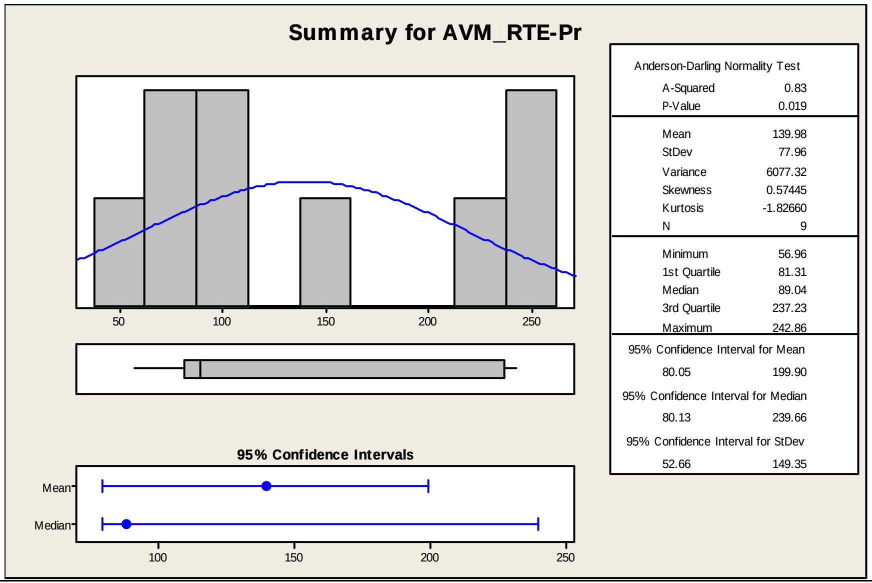
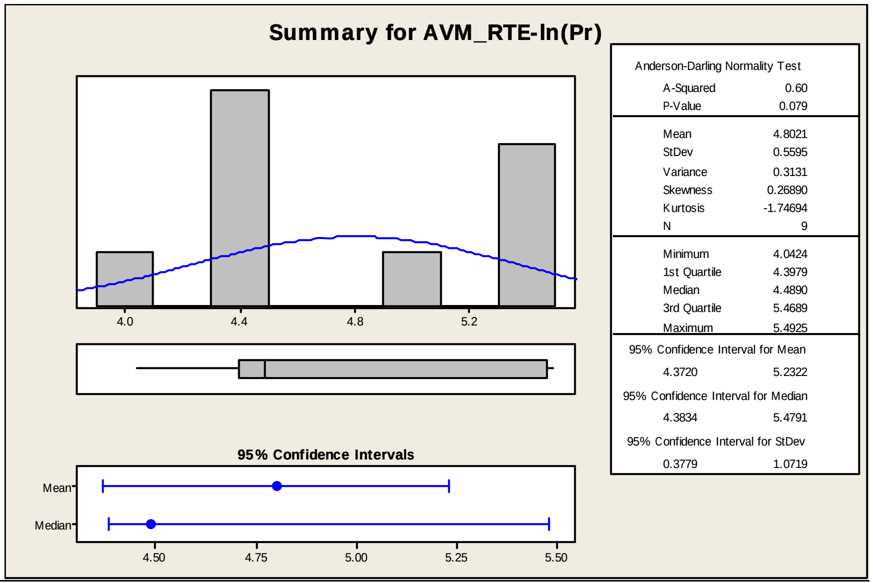
Non-Transformed	Transformed with F_t



Anderson-Darling Normality Test	
A-Squared	1.90
P-Value <	0.005
Mean	173.50
StDev	88.12
Variance	7764.96
Skewness	1.20981
Kurtosis	0.75188
N	31
Minimum	34.44
1st Quartile	121.76
Median	140.93
3rd Quartile	188.41
Maximum	389.56
95% Confidence Interval for Mean	
141.18	205.82
95% Confidence Interval for Median	
125.59	171.30
95% Confidence Interval for StDev	
70.42	117.79

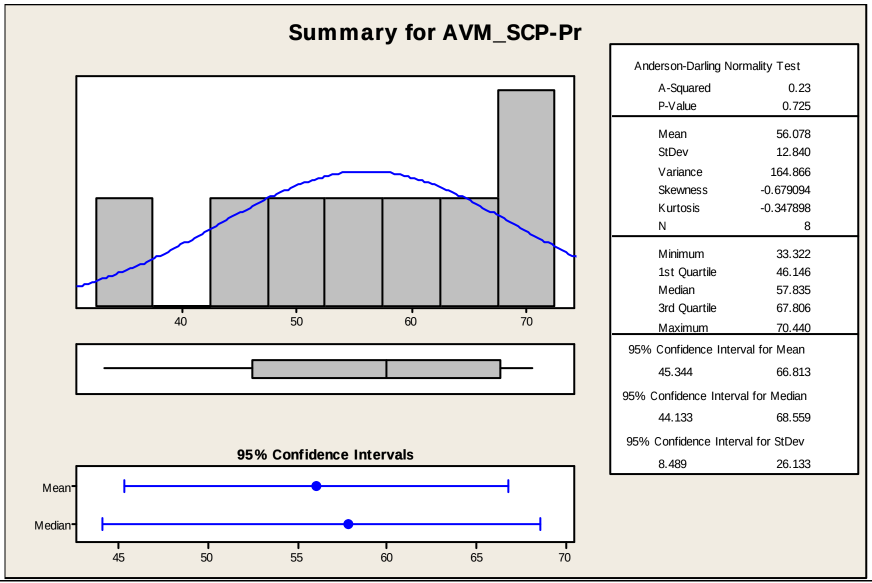


Anderson-Darling Normality Test	
A-Squared	0.72
P-Value	0.055
Mean	5.0396
StDev	0.4988
Variance	0.2488
Skewness	-0.32485
Kurtosis	1.75426
N	31
Minimum	3.5392
1st Quartile	4.8021
Median	4.9483
3rd Quartile	5.2386
Maximum	5.9650
95% Confidence Interval for Mean	
4.8567	5.2226
95% Confidence Interval for Median	
4.8330	5.1434
95% Confidence Interval for StDev	
0.3986	0.6667

Non-Transformed	Transformed with F_t
	

Anderson-Darling Normality Test	
A-Squared	0.83
P-Value	0.019
Mean	139.98
StDev	77.96
Variance	6077.32
Skewness	0.57445
Kurtosis	-1.82660
N	9
Minimum	56.96
1st Quartile	81.31
Median	89.04
3rd Quartile	237.23
Maximum	242.86
95% Confidence Interval for Mean	
80.05	199.90
95% Confidence Interval for Median	
80.13	239.66
95% Confidence Interval for StDev	
52.66	149.35

Anderson-Darling Normality Test	
A-Squared	0.60
P-Value	0.079
Mean	4.8021
StDev	0.5595
Variance	0.3131
Skewness	0.26890
Kurtosis	-1.74694
N	9
Minimum	4.0424
1st Quartile	4.3979
Median	4.4890
3rd Quartile	5.4689
Maximum	5.4925
95% Confidence Interval for Mean	
4.3720	5.2322
95% Confidence Interval for Median	
4.3834	5.4791
95% Confidence Interval for StDev	
0.3779	1.0719

Non-Transformed	Transformed with F_t
	Not Required

Anderson-Darling Normality Test

A-Squared	0.23
P-Value	0.725
Mean	56.078
StDev	12.840
Variance	164.866
Skewness	-0.679094
Kurtosis	-0.347898
N	8
Minimum	33.322
1st Quartile	46.146
Median	57.835
3rd Quartile	67.806
Maximum	70.440

95% Confidence Interval for Mean

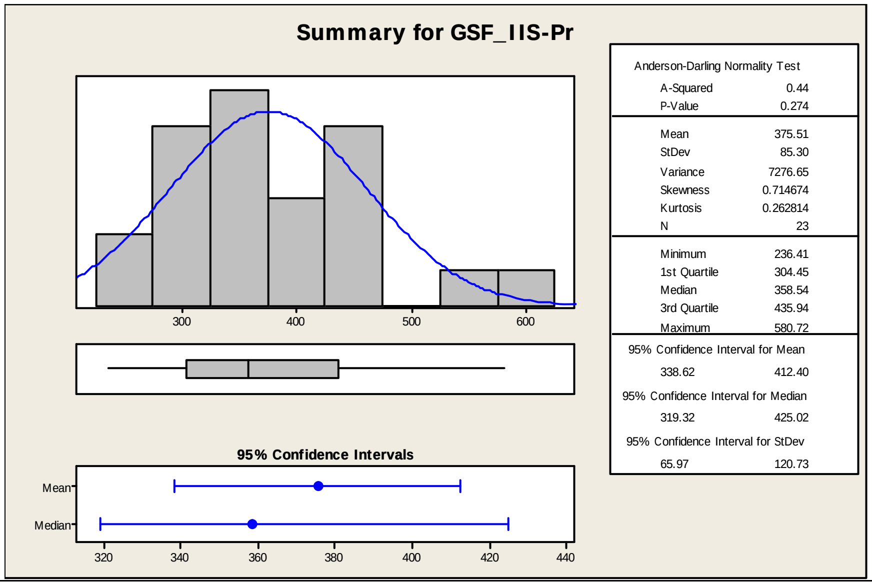
45.344 66.813

95% Confidence Interval for Median

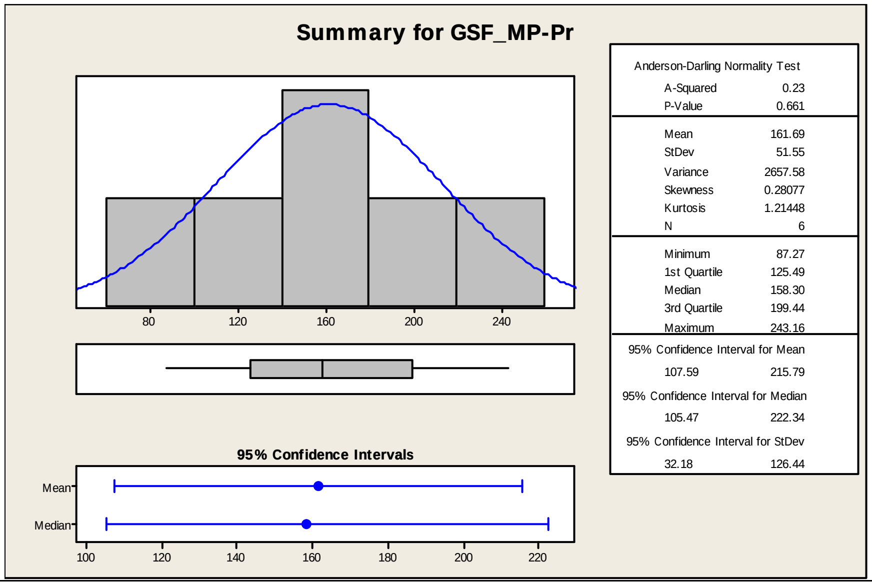
44.133 68.559

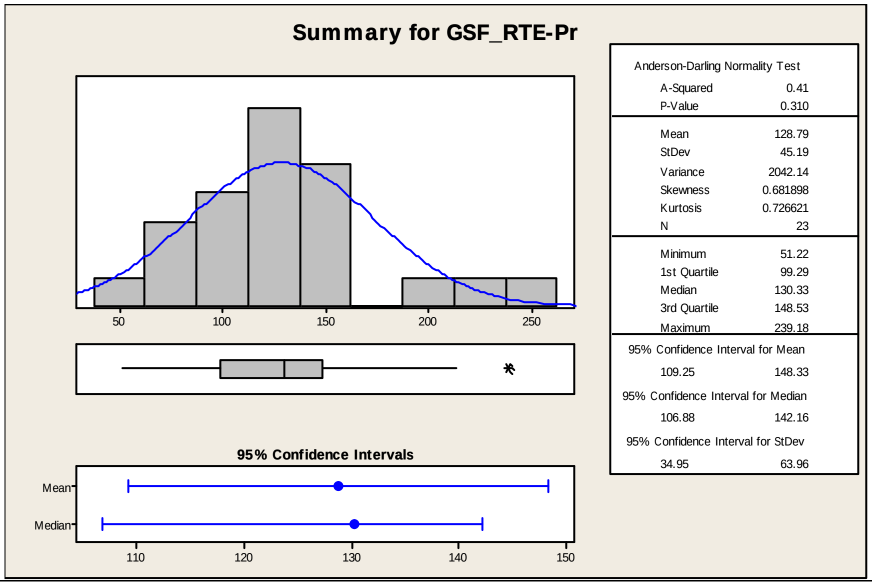
95% Confidence Interval for StDev

8.489 26.133

Non-Transformed	Transformed with F_t
	Not Required

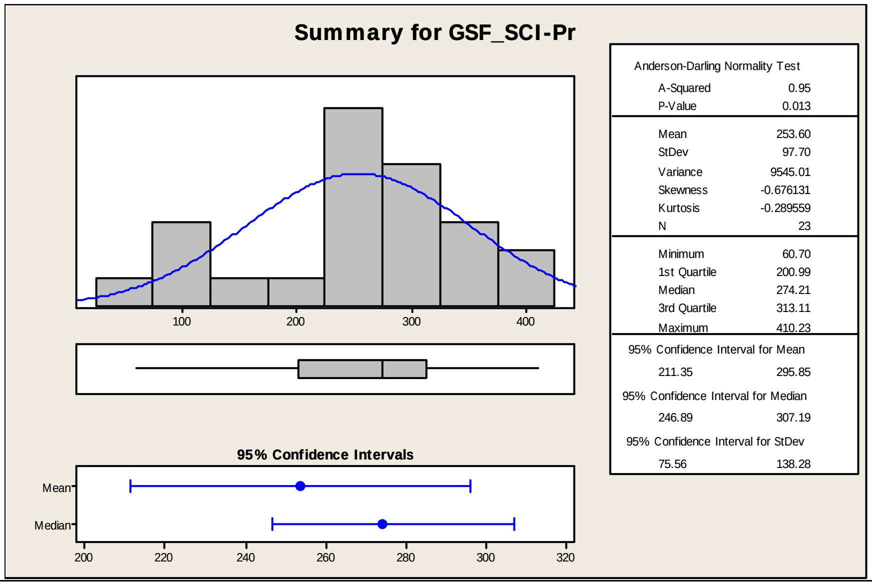
Anderson-Darling Normality Test	
A-Squared	0.44
P-Value	0.274
Mean	375.51
StDev	85.30
Variance	7276.65
Skewness	0.714674
Kurtosis	0.262814
N	23
Minimum	236.41
1st Quartile	304.45
Median	358.54
3rd Quartile	435.94
Maximum	580.72
95% Confidence Interval for Mean	
338.62	412.40
95% Confidence Interval for Median	
319.32	425.02
95% Confidence Interval for StDev	
65.97	120.73

Non-Transformed	Transformed with F_t
	Not Required

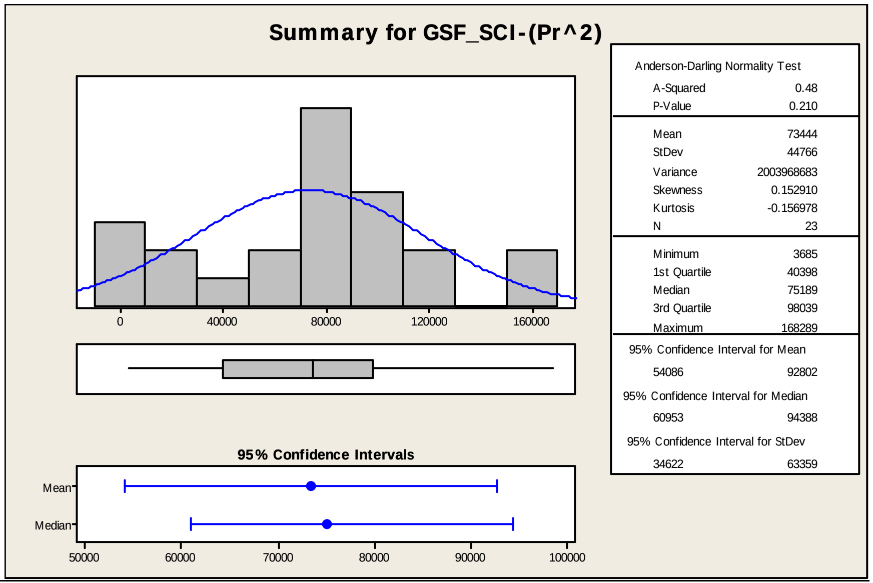
Non-Transformed	Transformed with F_t
	Not Required

Anderson-Darling Normality Test	
A-Squared	0.41
P-Value	0.310
Mean	128.79
StDev	45.19
Variance	2042.14
Skewness	0.681898
Kurtosis	0.726621
N	23
Minimum	51.22
1st Quartile	99.29
Median	130.33
3rd Quartile	148.53
Maximum	239.18
95% Confidence Interval for Mean	
109.25	148.33
95% Confidence Interval for Median	
106.88	142.16
95% Confidence Interval for StDev	
34.95	63.96

Non-Transformed	Transformed with F_t

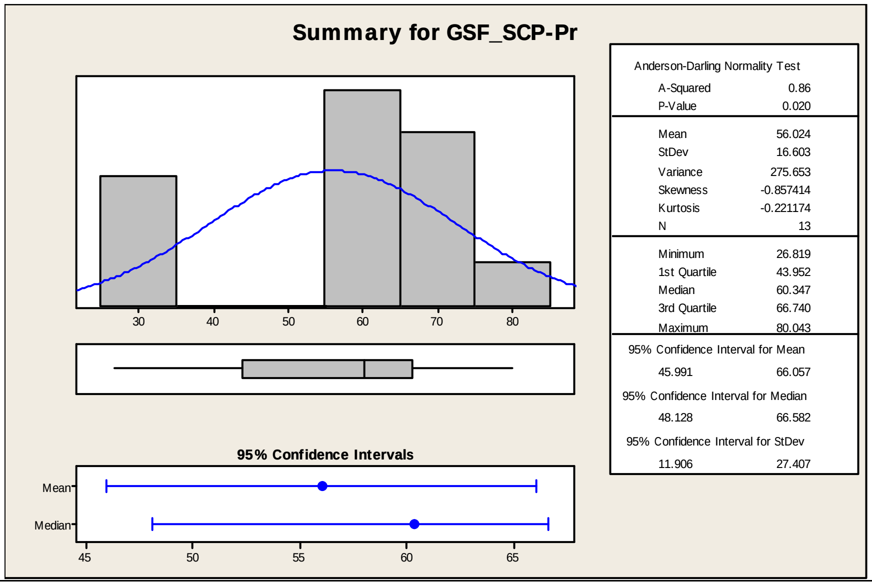


Anderson-Darling Normality Test	
A-Squared	0.95
P-Value	0.013
Mean	253.60
StDev	97.70
Variance	9545.01
Skewness	-0.676131
Kurtosis	-0.289559
N	23
Minimum	60.70
1st Quartile	200.99
Median	274.21
3rd Quartile	313.11
Maximum	410.23
95% Confidence Interval for Mean	
211.35	295.85
95% Confidence Interval for Median	
246.89	307.19
95% Confidence Interval for StDev	
75.56	138.28

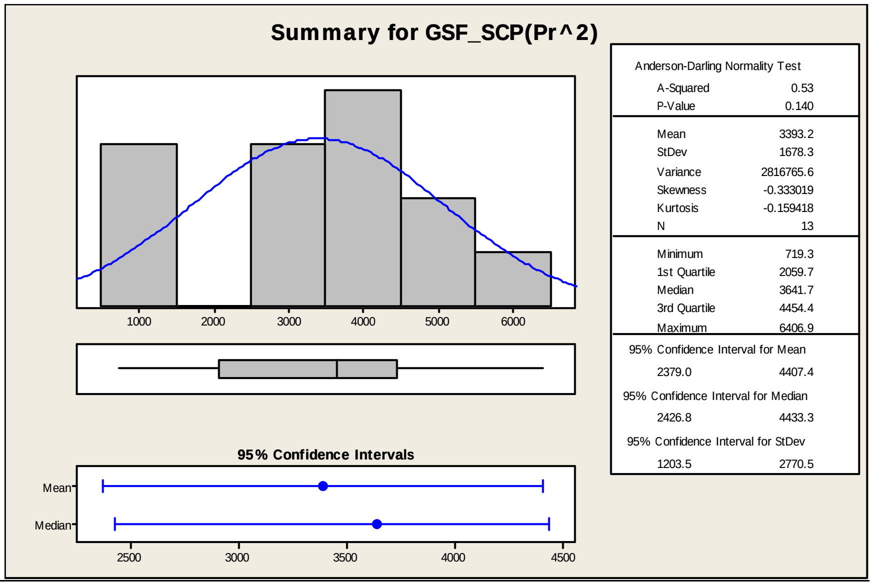


Anderson-Darling Normality Test	
A-Squared	0.48
P-Value	0.210
Mean	73444
StDev	44766
Variance	2003968683
Skewness	0.152910
Kurtosis	-0.156978
N	23
Minimum	3685
1st Quartile	40398
Median	75189
3rd Quartile	98039
Maximum	168289
95% Confidence Interval for Mean	
54086	92802
95% Confidence Interval for Median	
60953	94388
95% Confidence Interval for StDev	
34622	63359

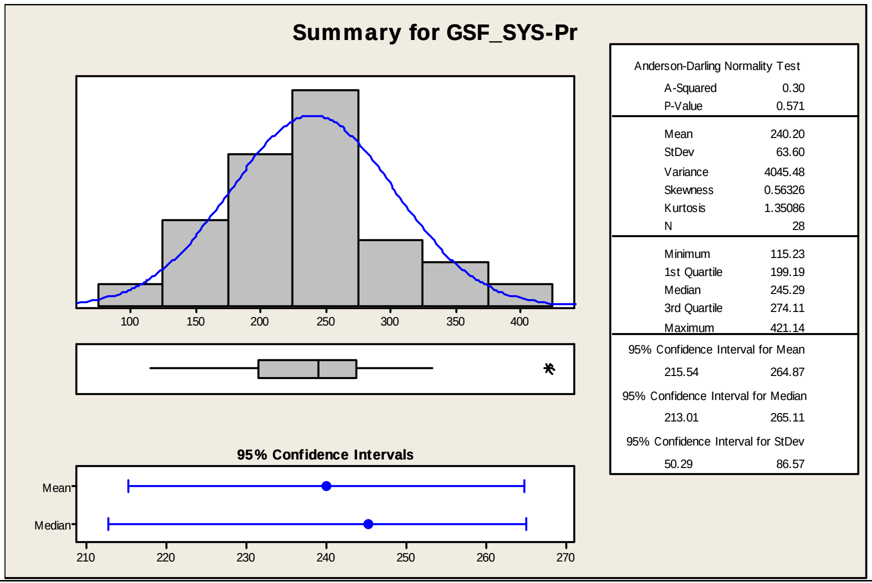
Non-Transformed	Transformed with F_t



Anderson-Darling Normality Test	
A-Squared	0.86
P-Value	0.020
Mean	56.024
StDev	16.603
Variance	275.653
Skewness	-0.857414
Kurtosis	-0.221174
N	13
Minimum	26.819
1st Quartile	43.952
Median	60.347
3rd Quartile	66.740
Maximum	80.043
95% Confidence Interval for Mean	
45.991	66.057
95% Confidence Interval for Median	
48.128	66.582
95% Confidence Interval for StDev	
11.906	27.407



Anderson-Darling Normality Test	
A-Squared	0.53
P-Value	0.140
Mean	3393.2
StDev	1678.3
Variance	2816765.6
Skewness	-0.333019
Kurtosis	-0.159418
N	13
Minimum	719.3
1st Quartile	2059.7
Median	3641.7
3rd Quartile	4454.4
Maximum	6406.9
95% Confidence Interval for Mean	
2379.0	4407.4
95% Confidence Interval for Median	
2426.8	4433.3
95% Confidence Interval for StDev	
1203.5	2770.5

Non-Transformed	Transformed with F_t
	Not Required

Anderson-Darling Normality Test

A-Squared	0.30
P-Value	0.571
Mean	240.20
StDev	63.60
Variance	4045.48
Skewness	0.56326
Kurtosis	1.35086
N	28
Minimum	115.23
1st Quartile	199.19
Median	245.29
3rd Quartile	274.11
Maximum	421.14

95% Confidence Interval for Mean

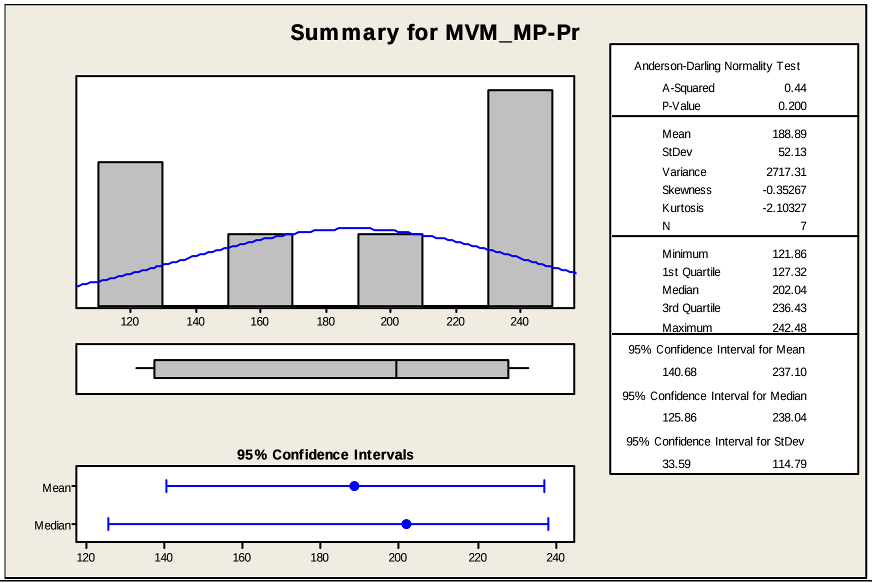
215.54	264.87

95% Confidence Interval for Median

213.01	265.11

95% Confidence Interval for StDev

50.29	86.57

Non-Transformed	Transformed with F_t
	Not Required

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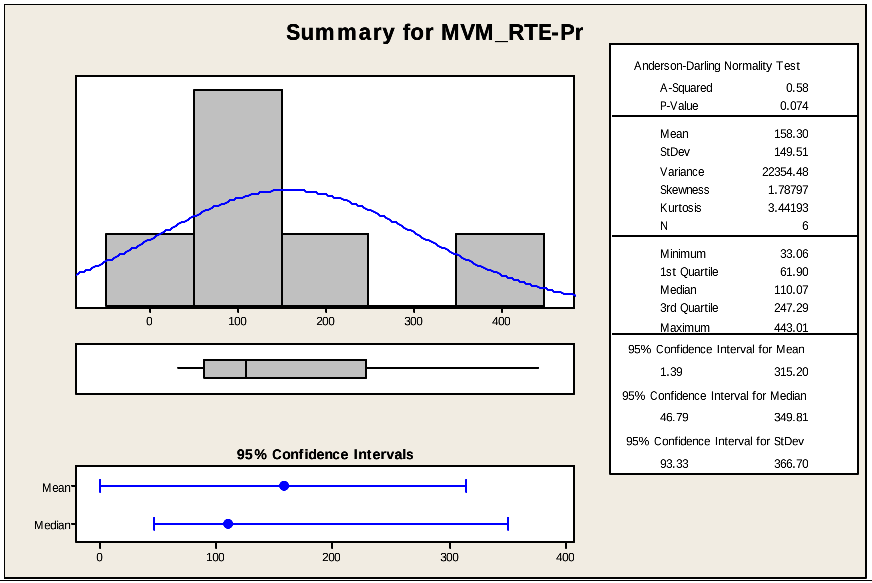
Anderson-Darling Normality Test
   A-Squared          0.44
   P-Value           0.200

   Mean             188.89
   StDev             52.13
   Variance        2717.31
   Skewness       -0.35267
   Kurtosis       -2.10327
   N                     7

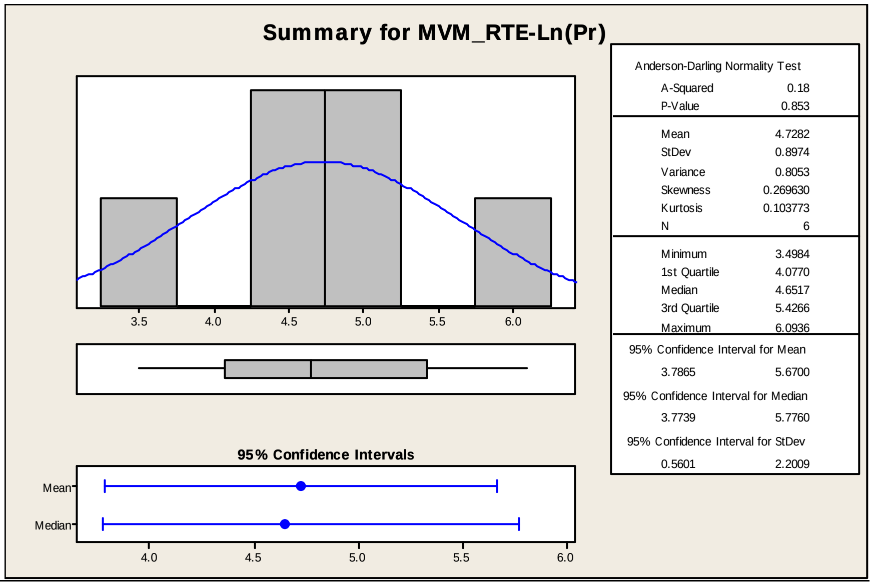
   Minimum          121.86
   1st Quartile     127.32
   Median           202.04
   3rd Quartile     236.43
   Maximum          242.48

95% Confidence Interval for Mean
   140.68           237.10
95% Confidence Interval for Median
   125.86           238.04
95% Confidence Interval for StDev
   33.59            114.79
```

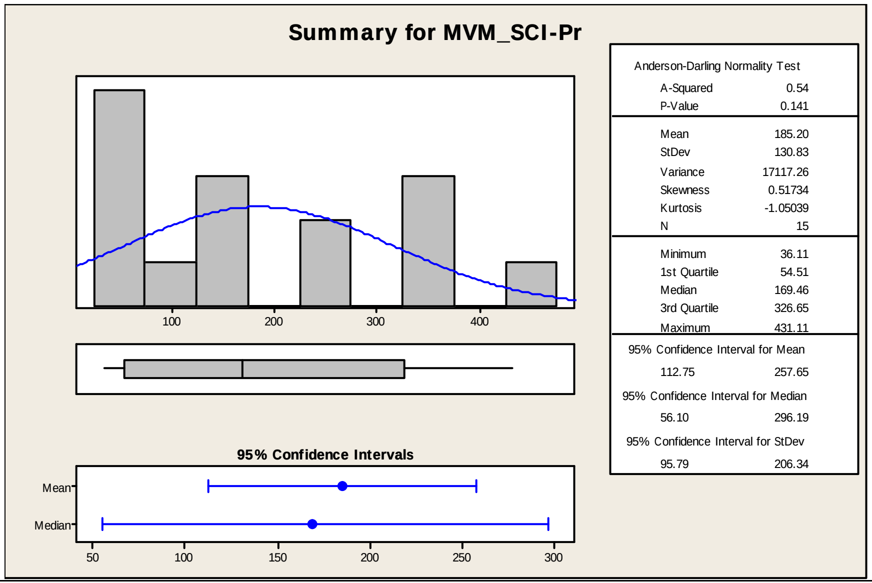
Non-Transformed	Transformed with F_t



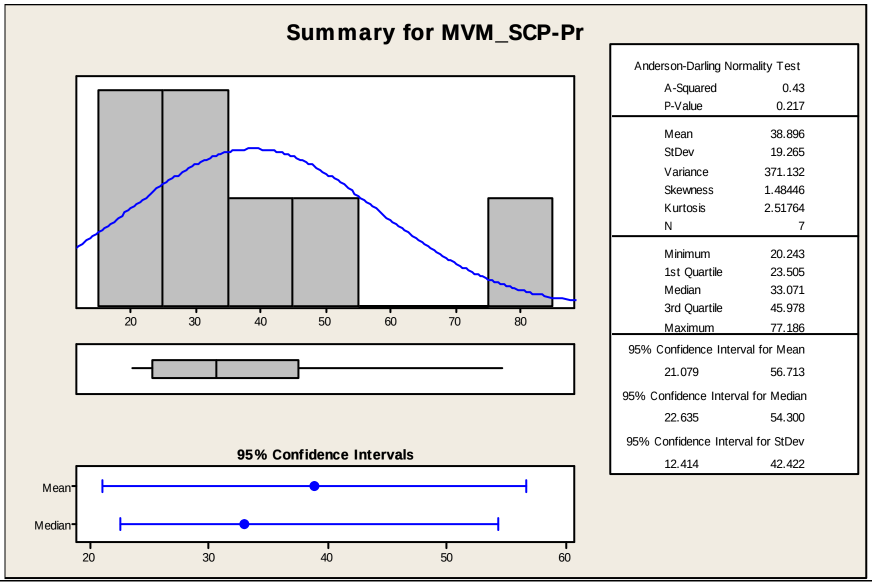
Anderson-Darling Normality Test	
A-Squared	0.58
P-Value	0.074
Mean	158.30
StDev	149.51
Variance	22354.48
Skewness	1.78797
Kurtosis	3.44193
N	6
Minimum	33.06
1st Quartile	61.90
Median	110.07
3rd Quartile	247.29
Maximum	443.01
95% Confidence Interval for Mean	
1.39	315.20
95% Confidence Interval for Median	
46.79	349.81
95% Confidence Interval for StDev	
93.33	366.70



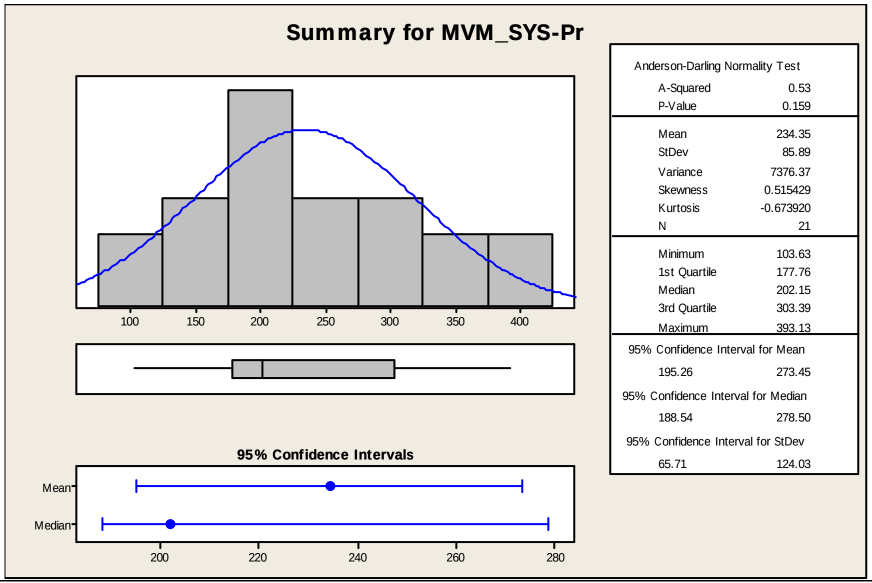
Anderson-Darling Normality Test	
A-Squared	0.18
P-Value	0.853
Mean	4.7282
StDev	0.8974
Variance	0.8053
Skewness	0.269630
Kurtosis	0.103773
N	6
Minimum	3.4984
1st Quartile	4.0770
Median	4.6517
3rd Quartile	5.4266
Maximum	6.0936
95% Confidence Interval for Mean	
3.7865	5.6700
95% Confidence Interval for Median	
3.7739	5.7760
95% Confidence Interval for StDev	
0.5601	2.2009

Non-Transformed	Transformed with F_t
	Not Required

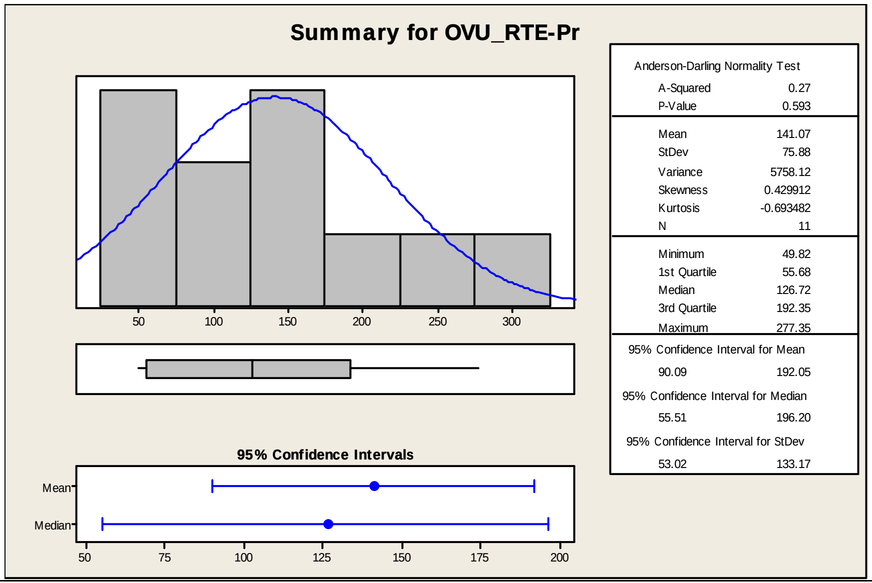
Anderson-Darling Normality Test	
A-Squared	0.54
P-Value	0.141
Mean	185.20
StDev	130.83
Variance	17117.26
Skewness	0.51734
Kurtosis	-1.05039
N	15
Minimum	36.11
1st Quartile	54.51
Median	169.46
3rd Quartile	326.65
Maximum	431.11
95% Confidence Interval for Mean	
112.75	257.65
95% Confidence Interval for Median	
56.10	296.19
95% Confidence Interval for StDev	
95.79	206.34

Non-Transformed	Transformed with F_t
	Not Required

Anderson-Darling Normality Test	
A-Squared	0.43
P-Value	0.217
Mean	38.896
StDev	19.265
Variance	371.132
Skewness	1.48446
Kurtosis	2.51764
N	7
Minimum	20.243
1st Quartile	23.505
Median	33.071
3rd Quartile	45.978
Maximum	77.186
95% Confidence Interval for Mean	
21.079	56.713
95% Confidence Interval for Median	
22.635	54.300
95% Confidence Interval for StDev	
12.414	42.422

Non-Transformed	Transformed with F_t
	Not Required

Anderson-Darling Normality Test	
A-Squared	0.53
P-Value	0.159
Mean	234.35
StDev	85.89
Variance	7376.37
Skewness	0.515429
Kurtosis	-0.673920
N	21
Minimum	103.63
1st Quartile	177.76
Median	202.15
3rd Quartile	303.39
Maximum	393.13
95% Confidence Interval for Mean	
195.26	273.45
95% Confidence Interval for Median	
188.54	278.50
95% Confidence Interval for StDev	
65.71	124.03

Non-Transformed	Transformed with F_t
	Not Required

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Summary for OVU_RTE-Pr

Anderson-Darling Normality Test
     A-Squared           0.27
     P-Value            0.593

     Mean              141.07
     StDev              75.88
     Variance         5758.12
     Skewness        0.429912
     Kurtosis       -0.693482
     N                     11

     Minimum            49.82
     1st Quartile       55.68
     Median            126.72
     3rd Quartile      192.35
     Maximum           277.35

  95% Confidence Interval for Mean
     90.09             192.05
 95% Confidence Interval for Median
     55.51             196.20
 95% Confidence Interval for StDev
     53.02             133.17
```

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